

Review of pollution in the African aquatic environment

CIFA
TECHNICAL
PAPER

25



Food
and
Agriculture
Organization
of
the
United
Nations



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edited by

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COMMITTEE
FOR INLAND FISHERIES
OF AFRICA
(CIFA)

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PREPARATION OF THIS DOCUMENT

This document is the collective presentation of the findings of the Working Party on Pollution and Fisheries, established in 1985 by the Committee for Inland Fisheries of Africa. The Working Party met in 1986 in Accra, Ghana, in 1989 in Nairobi, Kenya, in 1991 and 1993 in Accra, Ghana. Their Reports have been published as FAO Fisheries Reports No. 369, 437, 471 and 502.

DEFINITION OF MARINE POLLUTION

Pollution means the introduction by man, directly or indirectly, of substances or energy into the marine environment (including estuaries) resulting in such deleterious effects as harm to living resources, hazards to human health, hindrance to marine activities including fishing, impairment of quality for use of sea water and reduction of amenities.

IMO/FAO/Unesco-IOC/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP)

Cover photo: Small water body, Mbalmayo, Cameroon. Photograph by H. Naeve, FAO.

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ABSTRACT

This document summarizes the findings of the CIFA Working Party on Pollution and Fisheries. It gives advice on strategies for aquatic pollution control, including the establishment of environmental quality standards, emphasizing the use of risk assessment methodologies for arriving at site-specific environmental protection measures. The document further reviews the state of the African aquatic environment in respect of pollution by organic loads, by heavy metals and by organochlorine substances. It concludes that contamination of African inland waters, with the exception of some hot-spot areas, is still relatively low. Pollution by organic matter, causing eutrophication and anoxia, however, is identified as a major threat to fisheries. Although contamination with metals and organochlorines is still low, with the expected increases in urbanization and socio-economic activities, it is imperative to identify the sources and quantify the discharges of such material into the aquatic environment. The occurrence of synthetic micropollutants like organochlorine substances in different compartments of the aquatic environment, even at trace and ultra-trace levels, is of ecological and environmental health concern. Pollution control strategies should be formulated in all countries, covering legislation, environmental standards and criteria, waste minimization, effluent treatment, pollution monitoring, training, education and public awareness campaigns.

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TOWARDS MANAGEMENT OF THE AQUATIC ENVIRONMENT

by

D. Calamari and H. Naeve

1. EARLY STUDIES IN AFRICA

Based on a recommendation of the 20th Congress of the International Association of Limnology (IAL) held in Copenhagen, a IAL-UNEP Workshop on African inland waters was held in 1979 in Nairobi, the proceedings were published as "The Ecology and Utilization of African Inland Waters" (Symoens *et al.*, 1981).

The Workshop revealed that, compared to other areas of the world, information on African aquatic ecosystems were scarce and dispersed and certainly insufficient to produce acceptable bases for the management of aquatic resources, and concluded that:

- there is an urgent need to ensure a proper scientific basis for the planning, decision-making and management of Africa's aquatic resources;
- there is a real need to increase the number of African scientists trained in aquatic sciences, especially limnology, and to employ them in the utilization of the African water resources.

In 1970 FAO undertook a brief survey of inland water pollution in Kenya, Tanzania, Uganda and Zambia (Thorslund, 1971), concluding that, although water pollution was not then a serious problem in relation to freshwater fisheries, it could become so in the future as a result of increasing urbanization and industrialization.

After a decade other surveys were carried on in three more East African countries, i.e. Burundi, Malawi and the Sudan, and repeated in Kenya, Tanzania and Zambia, and in five West- and Central African countries, i.e. Mali, Côte d'Ivoire, Ghana, Nigeria and Cameroon (Alabaster, 1981; Calamari, 1985) under the following terms of reference:

- to identify existing and assess potential future sources of pollution affecting fisheries in the countries listed;
- to examine local capacity for dealing with fisheries aspects of water pollution; and
- to suggest appropriate infrastructure and establish baselines for future studies and monitoring programmes in the countries.

The results were reported to the Committee for Inland Fisheries of Africa (CIFA), concluding that an increase of pollution loads in aquatic ecosystems was observed as well as a decrease in water quality although not to the extent of a general acute problem in all the countries. The studies did show the need for cooperation at a regional level aiming at scientifically sound water pollution control measures and at the maintenance of a water

quality adequate to protect aquatic life and fisheries, identifying metals, organic pollutants with high biological oxygen demand and pesticides as major potential problems.

In 1985 CIFA decided to establish a Working Party on Pollution and Fisheries.

2. EXPERIENCES FROM THE EUROPEAN INLAND FISHERIES ADVISORY COMMISSION (EIFAC)

At the second Session of EIFAC (Paris, 1962), note was taken of a recommendation of the UN Conference on Water Pollution Problems in Europe (1961) that EIFAC should take the initiative in drawing up water quality requirements with respect to fisheries. EIFAC agreed that:

"the proper management of a river system demands that water of suitable quality be provided for each use that is made or intended to be made of it and that the attainment and maintenance of such quality is normally to be sought through the control of pollution. It was necessary, therefore, to know the standards of quality required for each particular use, in order to determine the degree of pollution control necessary and to forecast the probable effect of augmented or new discharges of effluents. It was pointed out that water quality standards for drinking water had been well defined by the World Health Organization (WHO) and that standards for certain agricultural and industrial uses are also well defined. However, water quality criteria for fish have not received the attention that they deserve. All too often, water has been considered quite adequate for fish as long as there has been no obvious mortality which can be ascribed to known pollutants. Degradation of the aquatic habitat through pollution and decrease in the annual production and subsequent harvest of fish have often passed unnoticed. With such reasoning in mind, it was agreed that the establishment of water quality criteria for European freshwater fish be undertaken by the Commission".

In this context, a "criterion" describes a water quality, defined by means of a critical review of scientific information, which will conserve the relevant structures and functions in the aquatic ecosystem. Unlike a standard, it does not carry a connotation, nor does it imply an ideal water quality. Water quality criteria should, therefore, be based exclusively on scientifically derived evidence and not be defined in an arbitrary manner. The assumption is made that for each substance reviewed a satisfactory data base exists from which a water quality criterion can be obtained.

The Working Party on Water Quality Criteria for European Freshwater Fish, established in 1962 as a result of the deliberations cited above, agreed at the outset that:

"Water quality criteria for freshwater fish should ideally permit all stages in the life cycle to be successfully completed and, in addition, should not produce conditions in a river water which would either taint the flesh of the fish or cause them to avoid a stretch of river where they would otherwise be present, or give rise to accumulation of deleterious substance in fish to such a degree that they are potentially harmful when consumed. Indirect factors like those affecting fish-food organisms must also be considered, should they prove to be important".

The emphasis of the Working Party has always been on the preparation of critical reviews of the literature, rather than compilations of published data, by experts with proven ecotoxicological experience with specific chemicals or other aspects of water quality. Draft reports were circulated to outside reviewers and ultimately discussed and approved by the Working Party (Lloyd and Calamari, 1987).

Generally the reports cover the following aspects:

- (1) Source, form and analytical method for the substance and its occurrence in water and sediments.
- (2) Lethal effects on fish, including (a) mode of toxic action; (b) acute and chronic exposures; and (c) factors affecting toxicity, e.g. age and size of fish, water hardness, temperature, dissolved oxygen and other pollutants.
- (3) Sublethal effects on fish, including bioaccumulation.
- (4) Field observations from surveys of polluted rivers and accidental fish-kills.
- (5) Effects on invertebrates (similar to (2) above) and aquatic plants.
- (6) Overview of published data, including scope for further research.
- (7) Proposal of tentative water quality criteria taking into account the influence of specifically important modifying factors, e.g. species of fish, pH, water hardness, etc.

During the past years, the Working Party has prepared reviews on temperature, dissolved oxygen, pH, finely divided solids, ammonia, monohydric phenols, chlorine, zinc, copper, cadmium, chromium, nickel, nitrite and aluminium.

It was, however, recognized that the common pollutants rarely occurred singly, and it was possible that the water quality criteria for individual substances would need to be made more stringent to allow for the added impact of other toxicants. Therefore, a critical review was made of the various models developed to describe joint action of toxicants, and all the available literature on the toxicity of mixtures to fish, invertebrates and plants was reviewed using a concentration/addition model. The conclusion finally reached is that, for the common pollutants reviewed by EIFAC, there may be some evidence for partial joint addition at low concentrations and, therefore, the values of the individual water quality criteria may have to be slightly reduced if other pollutants are present in significant amounts. Also, for chemicals which have a common toxic action on fish (such as many organic substances), their joint toxic action is additive at all concentrations.

Finally, the EIFAC technical papers were updated and published in two books (Alabaster and Lloyd, 1982; Howells, 1994).

In parallel with the programme of the Working Party on Water Quality Criteria, a group was set up to provide advice on fish toxicity testing procedures and associated terminology. To some extent, the need for such advice arose from the variable quality of the ecotoxicological data which had been critically evaluated as part of the reviews. It

was clear that tests should be carried out for well defined purposes - for initial screening of chemicals for toxicity, for enforcing effluent standards, and for monitoring river quality. Tests devised for one of these purposes were not necessarily useful for other investigations (Alabaster and Lloyd, 1982; EIFAC, 1983).

The EIFAC water quality criteria have been widely used as a basis for water quality control in Europe, and in some countries they have formed the basis for national water quality standards. Within the EEC, the criteria have formed the basis for water quality standards contained in the EC Directive on the quality of fresh water needing protection or improvement in order to support fish life (78/659/EEC) and, to a more limited extent, in the EC Directive on pollution caused by certain dangerous substances discharged into the aquatic environment of the community (76/464/EEC).

In the past, the attention of the Working Party has been directed towards common pollutants which have been identified as causing harm to fish. Because the importance of these substances has been recognized by the scientific community, a large data base was available for critical review and the tentative water quality criteria had a firm foundation. Pollution from these substances is, or should be, now under control in European rivers. The attention of regulators is now turning to the vast number of other, mainly organic, chemicals which may appear in freshwater as a result of man's activities.

This poses two main problems: First, the Working Party does not have the resources to carry out critical review on more than one or two substances a year so that progress would be much slower than that demanded by national and international political initiatives; however, this problem has been overcome to some extent by the recent preparation of some relevant critical reviews (although not generally as comprehensive as those of EIFAC in their scope) by other national or international organizations. The second problem is that, for many of these compounds, and especially for new chemicals, the data are inadequate even for the derivation of extremely tentative water quality criteria, with field data being non-existent.

3. THE RISK ASSESSMENT APPROACH

Recently, attention has been given by the scientific community to the "risk assessment" approach to prevent harm being caused by pesticides or other organic chemicals to aquatic life. In this context, a risk assessment is based on a comparison between the measured toxicity of a substance to aquatic organisms and the environmental exposure (a function of concentration and duration).

Although there is some general international agreement on the basic data package required for such an assessment, no guidance has been given on the way in which the data are evaluated in order to arrive at an assessment. For example, it is obviously unnecessary to obtain data from detailed and lengthy ecotoxicological studies on a chemical whose maximum predicted concentration in the aquatic environment based on very conservative estimates is many orders of magnitude lower than the acute toxic concentrations for fish and *Daphnia*. It is only when this margin of safety is small that refined estimates have to be made of both, the toxicity of the substance and the predicted environmental concentration. The former may be readily carried out using well-tried techniques, but the latter is more uncertain. Although several models have been produced

to predict the distribution of a substance in various environmental compartments, rates of biodegradation in the natural environment may be critical and difficult to quantify.

Within this rapidly developing and complex field, the scientific community is now focusing its attention on one aspect of aquatic toxicity prediction - the use of quantitative structure-activity relationships (QSAR). Basically, in this context, QSAR is the correlation of the toxicity of a compound with its physico-chemical properties.

During 1991/92 FAO, in a Technical Cooperation Project, used risk assessment as a tool to identify environmental problems in the Kenyan waters of Lake Victoria (Calamari *et al.*, 1994).

Such an exercise was considered of high interest and the Committee of Sponsoring Agencies of the Onchocerciasis Control Programme of the World Health Organization commissioned a similar study to assess the environmental impact of the recolonisation of the oncho free areas in the upper Léraba Basin, Burkina Faso, Côte d'Ivoire and Mali (Baldry *et al.*, 1994).

4. THE CIFA WORKING PARTY ON POLLUTION AND FISHERIES

After the CIFA Working Party on Pollution and Fisheries had been established in 1985, it was decided that its first report should be devoted to discussing the Scientific Bases for Pollution Control in African Inland Waters, taking into account the traditional experience of the industrialized world on pollution control and the new emerging approaches such as the risk assessment procedures and the preventive strategies which take care of the evolution of the pollution problems. This report was prepared in 1986 and published (Biney *et al.*, 1987).

Taking into consideration that relevant pollution problems had never been reviewed on at continental scale and existing information were scarce and scattered, it was decided to prepare critical reviews on the state of pollution in Africa looking at the three major contaminants identified in 1985 at the Sixth Session of CIFA, namely organic loads with elevated content of BOD (sewage and wastes from agro-alimentary industries), metals and pesticides.

The first two reviews were prepared in 1989 and 1991 and published (Saad *et al.*, 1990; Biney *et al.*, 1994). Pesticides, the third item identified, was considered a too complex subject and should have been subdivided. After a preliminary literature survey, however, documentation found was insufficient for most of the classes of pesticides, except for chlorinated hydrocarbon substances. It was therefore decided to limit the review to this group only. The review was prepared in 1993 and published (Osibanjo *et al.*, 1994).

In the meantime, regarding the state of the African freshwater environment, useful information on the impact of vector control operations have been reported and were reviewed by Dejoux (1988), in particular, the assessment of environmental impact of onchocerciasis control operations have been described (Lévêque *et al.*, 1989, Yameogo *et al.*, 1992).

Towards management of the aquatic environment

In the eight years of its existence, the CIFA Working Party on Pollution and Fisheries produced a document on the scientific bases for planning intervention and management of water resources in relation to pollution. Moreover three documents were prepared, collecting data on organic loads, metals and chlorinated hydrocarbon pesticides in African inland waters and reviewing the level of contamination by these three groups of contaminants. Finally, it promoted a study on risk assessment from land based sources in an important African lake that could be used as a model for other similar studies.

During its activities the Working Party involved several African scientists from various countries (Burundi, Cameroon, Côte d'Ivoire, Egypt, Ghana, Kenya, Nigeria, Seychelles and Tanzania), attempting to respond to the two recommendations from the SIL/UNEP workshop, an authoritative scientific group, cited at the beginning of this introduction.

The Working Party achieved its major goals in outlining the scientific bases for water pollution control and management and in evaluating the state of the African aquatic environment, reviewing the major groups of pollutants that could have negative impact on aquatic life and fishery resources.

The papers and reports prepared by the CIFA Working Party on Pollution and Fisheries have been re-edited and are presented in this volume.

SCIENTIFIC BASES FOR POLLUTION CONTROL

by

C. Biney, D. Calamari, H. Naeye, T.W. Maembe,
B. Nyakageni and M.A.H. Saad

1. INTRODUCTION

The awareness of the harm caused by pollutants to natural environments has led the political and legislative authorities of industrially-developed countries to introduce or review regulations to protect the environment. However, in recent years, all over the world and particularly in many countries in Africa, there has been a remarkable population growth, accompanied by an intense urbanization, an increase of industrial activities and a higher exploitation of cultivable land. These transformations have brought about a huge increase in the quantity of discharges and a wide diversification in the types of pollutants that reach river waters and have undesirable effects on fish and on the potential for fishery exploitation.

A few reviews exist on the state of pollution of African inland waters; see for example 'The Ecology and Utilization of African Inland Waters' (Symoens *et al.*, 1981) and 'Future Hazard from Pesticide Uses with Special Reference to West Africa and Southeast Asia' (Balk and Koeman, 1984). In the framework of the activities of the Committee for Inland Fisheries of Africa (CIFA), two reports were prepared on the state of pollution of African inland waters (Alabaster, 1981; Calamari, 1985). Eleven countries were considered: Burundi, Malawi, Sudan, Kenya, Tanzania and Zambia in the first survey; Mali, Côte d'Ivoire, Ghana, Nigeria and Cameroon in the second. The documents report on sources of water pollution, on relevant scientific research and on the legislation enforced in each country. Both reports concluded that pollution problems do exist, though in different degree, in the various countries. The need for improved legislation and expertise was recognized, since local authorities were in general well aware of the importance of the problem and willing to improve their action in the matter of water pollution control.

The purpose of this report is to examine and summarize what kind of research activities are needed to allow the adoption of regulatory measures based on scientific knowledge, for the effective control and prevention of aquatic pollution. In particular, it provides a strategy on how to deal with toxic substances, such as pesticides and heavy metals. Other types of discharges such as organic matter with high biological oxygen demand (BOD) and/or chemical oxygen demand (COD), suspended matter and nutrients, call for different consideration and a specific strategy of their own, as is the case with bacteriological pollution. It is, however, strongly recommended that control of these three types of pollution be well coordinated. An analysis is made here of how scientific knowledge is applied elsewhere, and how scientifically based regulatory actions may improve present methods of pollution control in Africa. Although socio-economic aspects are not taken into consideration in this report, it is clear that the environment is a resource for which the social price of degradation cannot be easily quantified. The cost of degradation in environmental quality can be very high, especially for future generations.

Among the prerequisites for decision-making, the following are important: political willingness, cultural attitudes and administrative capability. Consequently, there is a need to create public awareness of the deleterious effects of pollution and the dangers of incorrect application of chemical substances, particularly pesticides. In this connection, the potential role of non-scientific organizations in the preparatory phase of water pollution control activities is recognized. This report, however, concentrates on the role of scientific research in pollution control.

2. PROBLEMS IN THE DEFINITION OF WATER QUALITY CRITERIA

Water pollutants may be classified in many different ways, for instance according to chemical characteristics, physical state, environmental compartments in which they are discharged or found, sources, types of effects and target organisms which can be affected (Celamari and Chiaudani, 1984).

This paper concentrates on micro-pollutants, those elements or substances that are discharged as a result of human activities but which are present naturally in water bodies; any increase caused by man with respect to the quantities or concentrations present in unpolluted environments may have deleterious effects on organisms or ecosystems or modify biogeochemical cycles. This concurs with the concept of 'specific pollutant', defined by the Water Management Group of the Organisation for Economic Co-operation and Development (OECD) as a substance which, introduced into the environment essentially as a result of human activities, under given conditions reduces the quality of water due to its toxic effects on human beings and aquatic life. It differentiates 'specific pollutants' from the classic parameters such as BOD, COD and suspended matter. 'Specific pollutants' are also defined by other organizations as 'trace pollutants', 'micro-pollutants', or 'recalcitrant pollutants'. About 1 500 commonly detected molecules have been listed as such by the Water Research Centre in the United Kingdom (Holdgate, 1979) in the Index of Solubility, Toxicity and Biodegradability. About 30 elements, molecules or classes of substances have been included in the list of limits proposed for effluents in the Italian Law No. 319 for the prevention of water pollution (Marchetti *et al.*, 1973). Further, the Environmental Protection Agency (EPA) of the United States has set up quality criteria for water for about 40 elements or substances (Train, 1979). There is now a tendency in many countries to increase the number of substances to be regulated or kept under control.

The most commonly accepted definition of marine pollution is that given by GESAMP (IMO/FAO/Unesco-IOC/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection); this definition could, *mutatis mutandis*, also apply to fresh waters: "The introduction by man, directly or indirectly, of substances or energy into the marine environment (including estuaries), resulting in such deleterious effects as harm to living resources, hazards to human health, hindrance to marine activities including fishing, impairment of quality for use of sea water and reduction of amenities."

Pollution can limit possible uses of water and aquatic resources, and water quality criteria have been formulated therefore as a function of the various uses. Four main uses are taken into consideration here: drinking water supply, agricultural use, bathing and amenity, and aquatic life. Since for potable water the hygienic and sanitary aspects

require a specific scientific and regulatory approach, and agricultural and aesthetic uses are generally less demanding, quality criteria for aquatic life are generally considered as the most important. In Africa, where a majority of water bodies is subject to multiple use, the application of the more protective criteria would be even more justified.

In recent years there has been consolidation of the view that an aquatic ecosystem in which structures and functions are not disturbed possesses a quality which is immediately suitable, or suitable after simple treatment, for a variety of uses. This, together with the concept that every recipient body has a certain capacity to assimilate contaminants, has been the basis for the establishment of quality criteria for aquatic life by different international and national organizations (see EEC, 1978; Alabaster and Lloyd, 1982; Train, 1979; Marchetti *et al.*, 1973). On this basis, it is assumed that, for each pollutant, there is a margin of safety between the zero level, or the natural concentration, and the concentration at which undesirable disturbances can be observed. This margin can be identified and used quantitatively for establishing water quality criteria.

In general, water quality criteria are defined through the preparation of critical reviews of the scientific information available and by specifying on experimental evidence concentrations not to be exceeded. According to the European Inland Fisheries Advisory Commission (EIFAC), water quality criteria for freshwater fish should "ideally permit all stages in the life cycle to be successfully completed and, in addition, should not produce conditions in a river water which would either taint the flesh of the fish or cause them to avoid a stretch of river where they would otherwise be present, or give rise to accumulation of deleterious substances in fish to such a degree that they are potentially harmful when consumed. Indirect factors like those affecting fish-food organisms must also be considered should they prove to be important".

The scientific reports of EIFAC are usually prepared by working groups that discuss the chemistry of the pollutant in water, lethal action on fish, sub-lethal effects, type of toxic action, factors which influence lethal levels, field observations in polluted waters and data regarding toxicity to algae and invertebrates. Reports are concluded with a tentative quality criterion for aquatic life. Other bodies or organizations work in an analogous way. The scientific community has the responsibility to produce the basic data by experimental research and to provide the expertise necessary to assess the data and establish, by deduction, a sufficiently reliable quality criterion.

3. PROBLEMS IN THE APPLICATION OF WATER QUALITY CRITERIA

The terms 'standard', 'objective' and 'criterion' are frequently used indiscriminately, but the majority of research workers and people responsible for water quality management follow the definitions given by Warren (1971):

- The term 'standard' applies to any definite rule, principle or measure established by authority. The fact that it has been established by authority makes a standard somewhat rigid, official or quasi-legal; but this does not necessarily mean that the standard is fair, equitable or based on sound scientific knowledge, for it may have been established somewhat arbitrarily on the basis of inadequate technical data tempered by a cautious factor of safety. Where scientific data are sparse, such arbitrary standards may be justified.

Scientific bases for pollution control

- The word 'objective' represents an aim or a goal toward which to strive and it may designate an ideal condition. Most certainly, however, it does not imply strict adherence nor rigid enforcement by an agency or health department. It is gaining favour among engineers on boards and commissions that strive to achieve water pollution control by persuasive methods and cooperative action.
- A 'criterion' designates a condition defined by means of a critical review of scientific information and suitable to conserve structures and functions in the ecosystems. Unlike a standard, it carries no connotation of authority other than that of fairness or equity, nor does it imply an ideal condition.

To obtain the desired quality criterion or objective, two different approaches have been followed in different countries.

The first approach does not take into account the type and use of the water body receiving the contaminant but considers only the concentration of pollutants in the effluents. Uniform quality standards are set for any type of discharge (rigid effluent standards). These standards must necessarily be very restrictive in order to be effective since they have to protect even the most critical systems with a single regulation. As a result, the application of this criterion in many cases may lead to the requirement of a higher level of control than is necessary in the situation considered and hence to excessive and unnecessary costs, while more permissible limits may lead to a reduction in the level of protection. In fact, this procedure includes, by definition, neither the quantity of pollutant discharged over a period of time nor the number of discharges to the same receptor, and it does not take into account the receptive capacity of the water body. The main advantage lies in its ease of administrative management.

The second approach limits the quantity of the pollutant according to the characteristics of the receptor (river, lake, coastal waters) and of the pollutant (toxicity, persistence, bioaccumulation). This approach is favoured from many points of view because it requires, on a case-by-case basis, a treatment level which is suitable to the receptive capacities and the use for which the water is intended (flexible effluent standards). This procedure, therefore, is considered as the most economical overall, offering the highest reliability as regards the protection of the environment.

It might be concluded that the second approach would naturally be adopted in taking regulatory actions on effluents, but basic information is often needed on a number of elements:

- The receptive capacity of the water body. This implies a thorough knowledge of the type of receptor, its hydrological balance, with particular reference to the critical flow, dilution capacity, oxidizing capacity, chemistry, biological structure, thermal variations, relationship with ground water, and the existence of other sources of pollution and any other factor that can influence the maintenance of a safe concentration of the discharged pollutant.
- The development of the sources of pollution over time. This involves information on population characteristics and future trends of urban and industrial development, which has to be considered in accordance with the local situation and, obviously, within the framework of general economic planning.

In many countries, therefore, an intermediate approach has been followed so as to allow for adaptation of the effluent standards to a variety of receptors and the groups of pollutants. It also allows limits to be established in other compartments of the ecosystem rather than in water (e.g., in organisms or sediments).

For situations or countries where chemical analyses required to enforce effluent standards are not feasible, the practice of applying effluent toxicity standards has developed. By means of a relatively simple toxicity test (in general with fish) discharges or effluents are permitted or forbidden according to their toxicity. This practice is used particularly when chemical characterization of the effluents is difficult or when mixtures of chemicals have to be tested. An interesting review of experience in this approach in U.S.A. and Canada is given by Tebo (1986).

Recently, there has been a tendency to consider each case individually, to differentiate the approaches according to the type of pollutants, and, consequently, to establish different criteria for receptors with different characteristics.

Other approaches have been used, for example for mercury and phosphorus. For mercury, limits have been set for concentrations in fish or in sediments, since scientific findings do not allow to establish a quality criterion for water. For phosphorus, the theoretical discharges are relatively easy to calculate (quantify) and, from mass balance calculations, for lakes a water quality criterion of 10 µg/l has been set, in contrast to rivers, where the possibility of eutrophication is very limited.

A common simple approach is to classify potentially harmful substances in a 'black' and a 'grey' list; the 'black list' concerns substances not to be discharged at all, while the 'grey list' includes those substances which may be discharged within certain limits and under controlled conditions.

An adaptation of these approaches to water pollution control to suit African conditions (geographical and administrative) could be made.

4. AN AFRICAN EXPERIENCE: THE ONCHOCERCIASIS CONTROL PROGRAMME IN WEST AFRICA

An important use of pesticides in Africa lies in the public and animal health sectors to curb, if not to eradicate, endemic diseases such as malaria, onchocerciasis, schistosomiasis and trypanosomiasis through the control of their insect or mollusc hosts. It is of interest to analyze this specific use of pesticides in relation to (i) the possible impact on fishery resources, (ii) the measures taken to control undesirable effects and (iii) the protection of the environment.

One case for which information is available is that of the Onchocerciasis Control Programme (OCP). The brief summary below is mainly based on 'Ten years of onchocerciasis control in West Africa' (WHO, 1985) and on the review of Lévêque (1989) on aquatic biological monitoring. Other sources of information are the reports of the OCP Ecological Group.

4.1 The problem and the environment

The female of the black fly, *Simulium damnosum*, is the vector of dermal fileriosis (caused by the parasitic worm *Onchocerca volvulus*), which can result in blindness. The illness is prevalent along rivers, whence the name 'river blindness', as the larvae of these flies are aquatic and occur only in fast-flowing waters. In 1974, UNDP, FAO, World Bank and WHO launched a campaign for the control of the larval stages of the vector. About 18 000 km of rivers were treated weekly in several countries of West Africa. The rivers are of the savanna type, with a flood period (July-December) and a dry period (January-March/April) during which some of them dry up completely.

Before this programme was launched, little was known on the ecology of these rivers. A catalogue of aquatic insects and fish was therefore compiled, several studies were made of the river biology and an extensive monitoring programme was carried out prior to the treatments with pesticides.

4.2 Criteria applicable for the selection of larvicides

Several hundred insecticides were tested by OCP for their effectiveness against *Simulium*; for application in the programme, it was decided that any new larvicide should meet the following criteria:

- (a) The acute effects of a candidate pesticide, in the formulation and dose rate as appropriate for its use against *Simulium*, should not include reduction in the number of invertebrate species to a level at which their survival in a given locality would be endangered.
- (b) The pesticide should not give rise to the regional disappearance of any invertebrate species; the temporary (seasonal) local disappearance of some invertebrate species at the breeding sites of *Simulium* may have to be accepted.
- (c) The pesticide should not cause a long-term (i.e. extending beyond the next season) imbalance under normal conditions of application, i.e. marked shifts in the relative abundance of species should not occur.
- (d) The use of the pesticide should have neither direct impact on fish nor any effect on their life cycle.
- (e) Compounds likely to accumulate in the food web should be avoided.
- (f) In selecting pesticides for *Simulium* control in an area, account should be taken of human activities which, either by themselves or in combination with the vector control operations, might cause adverse effects on the environment.

4.3 Pollutant load

Temephos (Abate), a degradable organophosphorous insecticide with very low toxicity on mammals and fish, was the only molecule used in the first phase of the

programme (until 1979). Unfortunately, the development of resistance in insect populations led to the use of chlorphoxim, another organophosphorous insecticide with a higher toxicity to non-target fauna. In the meantime, a dispersible concentrate of the biological insecticide *Bacillus thuringiensis*, serotype H-14 (Teknar), began to be used successfully and it is increasingly employed (see Table I). However, *B. thuringiensis* H-14 is not effective during high-water conditions, and chemical insecticides have still to be used. In 1985, limited use of permethrin, an artificial pyrethroid, has been made in a restricted area with the consent of the Ecological Group.

Table I
Insecticide consumption (expressed in litres of marketed preparation)

Larvicide	1975	1976	1977	1978	1979	1980	1981	1982	1983
Abate C200	75631	129947	155615	215879	263377	184517	130000	162750	74807
Chlorphoxim						5713	70000	6699	35796
Teknar						416	1500	232986	310000

4.4 The aquatic monitoring programme

An extensive biological monitoring programme was set up at a number of stations in order to check on the possible short- and long-term effects on the communities of the treated rivers.

Overcoming a great number of scientific and practical problems, the monitoring programme on benthic populations and fish has operated since 1975, using national teams of scientists, locally available manpower and facilities. Short-term research was performed also on specific problems and at different ecological levels (phytoplankton, zooplankton). The invertebrate populations were studied by means of: (i) drift net sampling, (ii) Surber sampling (on rocky substrates in low-water periods), and (iii) fixed and floating artificial substrates. The state of fish populations was studied mainly by monitoring catch per unit of effort, variation in species composition, coefficient of condition and fecundity. A great number of publications on the results of the biological monitoring is available, and all are listed in the review by L  v  que (1989) already cited.

During ten years of monitoring, appreciable changes have occurred in aquatic insect populations, e.g., the disappearance of some Simuliidae, the rarefaction of other groups and the proliferation of Chironomidae; it is, however, difficult to attribute all the changes observed to pesticide treatments since hydrological fluctuations could also have played an important role. The results of the fish monitoring activities have shown that treatments have little or no impact and that no major changes occur in the fish catch or in the coefficient of condition and fecundity. It can be concluded that temephos has no discernible long-term effects on fish populations, and that some changes observed following the use of other insecticides are of only limited extent; moreover, also in this

casa, hydrological fluctuations may be responsible. On a long-term basis, the ability of insect populations from non-treated zones to recolonize the treated areas has been demonstrated.

Lévêque (1989) concludes that the results obtained after many years' treatment indicate that the larvicides employed had little effect on the non-target fauna. Although the first applications of temephos and chlorphoxim had fairly strong impact on invertebrate communities in the short term, it would seem that these conditions cease to exist fairly quickly after a year or less of successive applications. In operational conditions, the treated rivers seem to have fairly strong resilience and at any rate a great capacity for recovery. The situation is still improving with the reduction in the number of rivers treated, resulting from the success of the vector control, and with the increasing utilization of *B. thuringiensis* H-14, a pesticide exceptionally safe for non-target fauna.

Nevertheless, future activities, which include extension and improvement of biological monitoring, are envisaged. As a result of difficulties often encountered with routine chemical monitoring in Africa, only a few analyses of fish samples were made. Temephos was found to be present in fish muscle but levels sharply decreased a few days after the treatment. A new pilot project on chemical monitoring of fish is under consideration in relation to the use of new pesticides within OCP.

It appears that, in view of the intensive campaign of treatment and the possibility of *Simulium* developing resistance, efforts to detect undesirable effects have to continue, since the margins of safety between tolerable levels of chemicals and those provoking dramatic modifications in the environment have not yet been identified and are probably narrow.

4.5 Relevance of the programme to the work of CIFA

This brief description of the OCP environmental activities has demonstrated the feasibility and usefulness of different types of biological monitoring of African rivers. Vast experience already exists in some countries, by which a number of other countries can profit. Several methods have undergone large-scale testing under African conditions and have given good results. Local personnel have been adequately trained at individual level, and several institutes exist in which comprehensive experience has been gained. However, this is not the general situation for all countries involved in OCP, where the ability to perform biological monitoring is unequal.

5. RELEVANT AQUATIC POLLUTION RESEARCH PROGRAMMES SPONSORED BY THE UN SYSTEM

Within the framework of the UNEP Regional Seas Programme, four Action Plans covering African countries have been signed: the Action Plans for the Mediterranean, the Red Sea and Gulf of Aden, West and Central Africa and the East African Region (UNEP, 1982). Three Action Plans (Figure 1) comprise projects on marine pollution monitoring and research with components on analyses of metals and organochlorines in biota, oil pollution monitoring on beaches and in coastal waters, and bacteriological quality control of bathing waters (UNEP, 1983, 1985, 1988). MED POL (Mediterranean) has operated since 1975,

WACAF 2 (West and Central Africa) since 1983, while EAF 6 (East Africa) is at the planning stage. Although these projects deal with marine and coastal pollution, the structures created, including analytical facilities and capabilities in a number of research centres, are undoubtedly of interest and relevance to any pollution research projects to be established under CIFA.

Programmes and projects in the freshwater sector also are being executed by the UN system, e.g., the ONCHO Programme (Section 4) and the WHO/UNEP GEMS-Water Project, a world-wide programme aiming at monitoring of freshwater systems, improving the validity and comparability of water quality data and assessing trends of water pollution.



Figure 1. Coverage of relevant UNEP Action Plans in Africa

6. SCIENTIFIC RESEARCH: TRADITIONAL AND NON-TRADITIONAL TRENDS

Part of the scientific community endeavour to elaborate more precise quality criteria, a 'traditional' approach. For a higher degree of precision of the criteria, these scientists take into account, for instance, the chemical and biological transformations which might occur, and study the statistical distribution over time. Work is also being done to develop criteria for substances which had not been considered previously. This conventional approach has good reasons to exist, as demonstrated by the critical reviews of Sprague (1976) and Thurston (1979). They underline that for a great number of pollutants no criteria exist and that only about 50% of the criteria proposed can be considered acceptable or would be acceptable if somewhat modified; the rest are inadequate and need correction. They also stress the need for more information on

identified pollutants, i.e. the chemical behaviour of the molecule, environmental fate, toxicity of the principal forms and possible transformation and bioaccumulation.

Another issue that needs experimental study concerns mixtures of toxicants; divergent positions have been taken by two competent organizations. In Water Quality Criteria, 1972 (NAS/NAE, 1973), the U.S. EPA maintains that, in the presence of a mixture of pollutants at a No Observable Effect Concentration (NOEC), it is necessary to lower the water quality criteria, i.e. to reduce to a fraction, the acceptable level for each of the pollutants present. The EIFAC Working Party on Water Quality Criteria for European Freshwater Fish, after extensive review of the literature on mixtures of toxicants, concludes instead that experimental evidence suggests that the proposed quality criteria for individual toxic substances could be applied also in cases where several pollutants are present (EIFAC, 1980; Alabaster and Lloyd, 1982). However, reviewing the subject in 1986, the EIFAC Working Party concluded on the basis of recent research on organic chemicals that low concentrations at no-effect level of such substances may still exert a harmful effect when present in mixtures (EIFAC, 1987; Howalls, 1994). Pending further research, it is prudent to assume that the effects of chemicals in mixtures are additive at very low concentrations. Thus individual water quality criteria may have to be slightly reduced if other pollutants are present in significant amounts. This shows that even 'traditional' approaches serve to fill gaps in knowledge or at least to clarify controversial points.

'Non-traditional' research follows two main currents: one aims at forecasting, as far as possible, the effect and the fate of pollutants in ecosystems, the other at the definition, in quantitative terms, of biogeochemical cycles. Both tend towards producing information necessary for control measures prior to discharge of pollutants.

Several substances have been banned recently because of their marked effects on the environment and on human health. There is now pressure to evaluate the risks inherent in new chemical substances in advance of their production on a commercial scale. A similar approach has been proposed for substances already in use and produced in very large quantities for which insufficient information exists. Different screening methods have been developed for such evaluations. On the basis of a wide debate (see, for example, the Chemical Testing Programme, OECD) agreement has been reached on chemical properties to be measured and the toxicological tests to be performed to define the degree of hazard of the various substances (Integrated Rating System (IRS); Schmidt-Bleek *et al.*, 1982).

Another approach is the application of the Quantitative Structure-Activity Relationships (QSAR), proposed by Hansch (1969, 1973). Recent experimental work indicates the possibility of attaining a high degree of predictability, with substantial agreement between expected and observed toxicity levels within relatively homogeneous classes of organic chemicals. In some cases the hydrophobic characteristics, expressed by the logarithm of the *n*-octanol/water partition coefficient ($\log P$), were sufficient to give high correlation with the toxic activity of the molecules. Good results have been obtained for several industrial organic chemicals (Veith *et al.*, 1983; Konemann, 1981; Hermens *et al.*, 1984; Calamari *et al.*, 1983). Electronic characteristics (pK_a) are a determinant factor in the toxicity of several amines (Calamari *et al.*, 1980). The toxic activity of phenols, chlorophenols, chloro- and alkylanilines is adequately described by a biparametric equation (Hermens *et al.*, 1984; Saarikoski *et al.*, 1986). In other cases, $\log P$ alone, although significantly correlated with the toxic effect, was not sufficient to give good

predictability. For example, a study by Vighi and Calamari (1985) on organotin compounds showed good predictability only within the different subclasses (mono-, di-, tri- and tetrasubstituted). Better results, with very high predictability, have been obtained with a biparametric equation, introducing electronic or steric parameters as pK_a or molecular connectivity indices ($^1\chi$ and $^2\chi$). The usefulness of molecular connectivity in structure activity relationships has also been demonstrated for several other compounds (Schultz *et al.*, 1982; Sabljic, 1983).

Basak *et al.* (1984) found quantitative correlations between toxicity and structure of several organic esters with a multi-parametric relationship which included a lipophilic (log P), an electronic ($^1\chi$) and a steric parameter (CIC).

From the few examples quoted and the ample literature available, Konemann and Calamari (1983) stated that:

- QSAR have been developed for several classes of chemicals and allow, within these classes, good estimates of toxicity of chemicals.
- Most QSAR have been calculated for a limited number of chemicals. Expert judgement is necessary to indicate the boundaries of the validity of QSAR.
- If used in a proper way QSAR can be very helpful for selecting priority chemicals, if experimental data are not available.

Until recently, the application of the QSAR only to homogeneous groups of chemical substances was a limitation. A wider application of this approach will provide more accurate and scientifically reliable lists of dangerous substances.

The second 'non-traditional' approach aims at the definition in quantitative terms of the biogeochemical cycle of the various molecules or elements.

Simulation models and tests in partially-controlled ecosystems quantitatively define the biogeochemical cycles in more accurate form than earlier work on pesticides (Matcalf *et al.*, 1971); they are certainly more practical than the gigantic detailed models constructed for some pollutants, e.g., DDT (Randers, 1973). Such research aims at determining a Predicted Environmental Concentration (PEC) on the basis of a few physico-chemical parameters. The degree of affinity of chemicals to the fundamental environmental compartments (water, air, soil, biota) is assessed on the basis of four physico-chemical properties: S - water solubility; H - Henry's constant; K_{oc} - soil absorption coefficient; K_{ow} - *n*-octanol/water partition coefficient. Values for these parameters can be measured experimentally or calculated by means of a property correlation equation (Kenaga and Goring, 1980). On the basis of this simple approach calculations can be made using models such as the fugacity model of Mackay and Paterson (1981) or the Predicted Environmental Distribution (PED). More complex models based on the same principles are the Quantitative Water, Air, Sediment Interaction model (QWASI) (Mackay *et al.*, 1983, 1983a) and the Exposure Analysis Modelling System (EXAMS), developed by EPA (Burns *et al.*, 1981).

However, the PED is of limited help in predicting the final concentration of a molecule in a given environment, since a molecule in contact with the environment could

have different fates according to its characteristics and those of the environment. Basic processes affecting the molecule are photolysis, photo-oxidation, redox and other types of chemical reactions with other molecules present in the environment, and biodegradation and metabolism.

Few attempts have been made to specify data on organic chemicals needed to predict their environmental fate; however, some information is available (see, for example, Haque (1980) and Hutzinger (1980, 1982)). More data are available on biodegradability, and the persistence of a number of substances can be predicted, although methods for studying biodegradation are still controversial (Gerike and Fisher, 1979, 1981). Metabolism, although important for organisms, plays in general a minor role in the quantitative transformation of environmental contaminants. When data are available, a transformation matrix can be prepared and, using the time of persistence, the PEC can be calculated. In this context, physical dispersion and the characteristics of receiving waters have to be taken into account.

Utilizing these new approaches, it is possible to formulate a scheme of environmental management to take account of the assimilative capacity (absorption, transformation and storage) of each environmental compartment. At legislative level, the new approach is acknowledged in laws on new chemical substances such as the Toxic Substances Control Act in U.S.A. (U.S. EPA, 1978) and the 6th Amendment to Directive 831/79 on Dangerous Substances in the European Economic Community (EEC, 1979). The current view is that pollution prevention is preferred to *post hoc* control. A policy of prevention implies that toxicological characteristics of molecules are known before a chemical is marketed. Consequently, the prediction of damage is a key issue in scientific and regulatory activities and most of the ecotoxicological studies are directed to its improvement.

7. THE RISK ASSESSMENT APPROACH

In an editorial in 'Environmental Toxicology and Chemistry', Kimerle (1986) raised the provocative question: 'Has the water quality concept outlived its usefulness?'. Since the fifties this concept has been the scientific basis for any water quality control. During the seventies, when a shift from control to prevention took place, it was realized that control of conventional pollutants alone was an inadequate strategy. Moreover, with the improvement of waste treatment technology, a higher reduction of toxic inputs was envisaged. Three additional reasons lead towards a different strategy in pollution control: (i) the need to protect the whole environment and not just one or the other of the compartments (water, air, etc.) or an identified target species; (ii) the huge quantity of information necessary to formulate water quality criteria, and (iii) the great number of chemical substances actually used by man as well as the variety of chemical groups to which these substances belong.

Simply as an example, the EIFAC Working Party on Water Quality Criteria in more than twenty years has produced only 15 reports and the U.S. EPA 'Red Book' contained only 53 criteria in 1976. On the other hand, in the European Economic Community about 10 000 chemicals are widely used. To overcome this problem, EPA proposed in 1983 a simplified method of deriving a water quality criterion (Stephan *et al.*, 1983); the method required 16 acute tests on different animal species, 3 chronic tests, 2 tests on plants and

one bioconcentration study. This proved a too complex procedure to speed the preparation of all criteria documents necessary for an appropriate water pollution control.

One can assume that no exposure means no need for toxicity data. This simple concept highlights the importance of exposure, and it was realized that a toxicological criterion is only part of the pollution control strategy. Obviously, it is not necessary to conduct very complex toxicological studies when, at a first estimate, the predicted concentration of a substance in the environment will be very low or several orders of magnitude less than the acute toxic concentration.

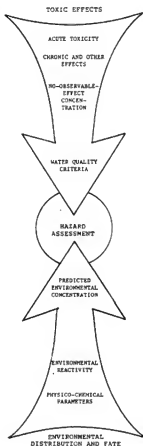


Figure 2. Scheme of the relationships existing among exposure, effects and risk assessment

The Risk Assessment approach (Fig. 2, Calamari, 1984) has become popular in the scientific community and with administrators involved in regulatory and control activities. In-depth toxicological investigations are necessary only when the predicted environmental concentration is not far from the No Observable Effect Concentration (NOEC) derived from relatively simple toxicological tests or even data on acute toxicity. The value of this approach lies in the possibility of managing a higher number of chemicals for which there are limited toxicological data.

An outline of Risk Assessment is given by Bro-Rasmussen and Christiansen (1984). The prediction of the environmental concentration of a substance starts with the determination of a few basic parameters such as physico-chemical characteristics and production and/or emission data to ascertain the distribution and mobility of the chemical in the environment. Then the persistence is evaluated from data on chemical or biological degradation in the various compartments. The toxicological studies to follow will provide acute and chronic toxicity data; studies of microecosystems need only be conducted when the data on potential exposure show there is cause for concern.

In general, it is easier to obtain information on production and use and data on physico-chemical characteristics than toxicological data, so simple calculations or scenarios can be of great help in pollution control management. However, the problem is not always simple and at least 30 types of approaches to Risk Assessment have been proposed (Hushon, 1982).

Under African conditions, where basic ecotoxicological data are frequently scarce or even nonexistent, Risk Assessment could provide a preliminary step. For example, for a pesticide, data on quantities entering into a country and the extent of the area treated, are relatively easy to obtain; the basic physico-chemical characteristics can be taken from handbooks or obtained from the manufacturers. Then the mass balance and the theoretical concentration can be calculated for each water body from available data. Acute toxicity data from the literature can provide the basis for an approximate toxicological evaluation. By comparing the PEC in water, sediments or fish with acute toxicity data, one can decide if direct research on the chemical is necessary, and if reduction in the quantities applied or alternative options (other chemical to be used) are needed in order to protect the environment.

8. CONCLUSIONS

For water pollution management in the African continent, several strategies are available for limiting undesirable effects as well as for pollution prevention. Considering the limited resources available, a number of methodological approaches are proposed; they can be used in sequence, from the simple to the more complex, or in combination.

The concept that water quality criteria are the basis for any kind of water pollution control policy is certainly valid. However, data from industrialized countries with temperate ecosystems should only be applied with caution to African conditions since toxicity, persistence and accumulation rates will either be higher or lower, depending on the substance. Comparative toxicity studies are therefore needed, even if these are, for example, simple short-term tests under static conditions to assess the toxicity of a few

chemical substances and effluents on one or two species of native fish (e.g., *Tilapia sp.* and another) or eventually a crustacean or mollusc.

The following is a proposal for a general scheme for pollution management:

- Collection of basic data on all existing sources of pollution by means of national surveys, calculation of the theoretical loads.
- Evaluation of the state of water bodies by means of simple chemical analyses and biological monitoring. (This could be an important task in several countries).
- Evaluation of the potential damage to fisheries through review of literature data, toxicity testing with local species and, whenever possible, chemical analyses of environmental matrices.
- Establishment of safe effluent 'standards' and compilation of a 'black' and a 'grey' list of dangerous substances.
- Determination of 'environmental objectives' for recipient waters using water quality criteria appropriately modified on the basis of those proposed outside Africa.

For management of polluting discharges, the following strategies can be applied:

- (a) Limitation of the effluents by means of a *rigid effluent standard*, both with chemical concentration limits and/or with a toxicological limit derived by simple acute toxicity tests on effluents. This does not take into account the specific characteristics of the receiving water body.
- (b) Limitation of the effluents by *flexible effluent standards*. In this case, the limits are calculated in order to maintain water quality criteria in a *specific water body*. Also in this case the limit can be defined as chemical and/or toxicological. Values and limitations of these approaches have been discussed in the previous chapters.
- (c) For some chemical substances it is scientifically unsound, and insufficient to protect the environment, to set up 'objectives' or 'criteria' for water (the classical case is mercury). In such cases it is necessary to indicate objectives or criteria for another environmental compartment or matrix (for example sediments or fish).
- (d) Sometimes, with particular environments and for certain chemical substances, a species is shown to be particularly sensitive (crustaceans to pesticides, for instance). In such cases, an 'indicator species'-oriented management has to be preferred to the water quality criterion approach.
- (e) The classification of chemical substances in use in a country into 'black', 'grey' and 'white' lists can be of help, especially in the framework of a Risk Assessment approach to water quality control (i.e. the comparison of predicted environmental exposure with available toxicity data). This does not necessarily mean that the black list chemicals are to be totally banned but that they should be used only on certain conditions and under strict control (such as for PCB for certain industrial activities in Europe).

Scientific bases for pollution control

Finally, it should be noted that the control and management of water quality in the general interest of society implies the choice of priorities and objectives, the selection of criteria through which the quality must be verified in relation to fixed objectives and, finally, the definition of standards for the criteria chosen in order to pursue and achieve the goals. The establishment of the objectives is essentially an administrative decision made on the basis of social, economic and technological considerations, taking into account the divergent interests of the different users of water. The actual management of water resources thus depends on the choice of appropriate objectives, on the basis of which it is possible to advise on optimal and often simple methods for water quality management.

DOMESTIC AND INDUSTRIAL ORGANIC LOADS

by

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1. INTRODUCTION

Over the last years, in many African countries a considerable population growth has taken place, accompanied by a steep increase in urbanization, industrial and agricultural land use. This has entailed a great increase in discharge of pollutants to receiving waters, causing undesirable effects on the aquatic environment and on fisheries.

Organic pollution of inland waters in Africa, in contrast to the situation in developed countries, is often the result of poverty and economic and social under-development. According to Tolba (1982), it is in these countries that the quality of water, and often the quantity, is lowest, sanitation and nutrition the worst and disease most prevalent.

Unfortunately, there are very few water quality studies for most African inland waters. In general, the available data come from scattered investigations which were carried out by individuals and by very few scientific projects concerned with African waters. Few reviews exist on the state of pollution of African inland waters, e.g. Dejoux *et al.* (1981), Alabaster (1981), Calamari (1985), Burgis and Symoens (1987), Dejoux (1988) and Davies and Gesse (1988). All documents confirm the existence of pollution problems at various levels in the different countries.

2. IMPACT OF ORGANIC WASTES

Due to population and industrial growth, inland waters (rivers, lakes, etc.) become often the recipient of organic matter in amounts exceeding their natural purification capacity, while in the past natural purification and dilution were usually sufficient.

Sewage and other effluents rich in decomposable organic material, cause primary organic pollution. Secondary organic pollution is defined as the surplus of organic matter, which is the sum of undecomposed organic material introduced into the water body with primary pollution and of the material resulting from an extremely increased bioproductivity within the polluted ecosystem itself (Stirn, 1973). As stated by Dejoux *et al.* (1981), organic wastes mineralize in the receiving water bodies and the resulting nutritive elements stimulate plant production, leading to eutrophication. In this situation, the biomass increases considerably and goes beyond the assimilation limit by herbivores. This secondary organic pollution is considerably greater than the primary organic load. The excessive production of organic matter leads to the build up of "sludge" and the mineralization process consumes all dissolved oxygen from the water column, which causes fish kills. Consequently, organic pollutants are called oxygen-demanding wastes. The relatively high temperatures in tropical countries accelerate this process.

3. SOURCES AND TRANSPORT OF ORGANIC LOADS

Rain water transports soil to streams, rivers and lakes by erosion processes, including dissolved and particulate organic matter. Decomposition of this organic matter continues during transport and in the sediments, giving new soluble organic and inorganic matter. The quantities of organic matter transported, its characteristics and composition vary from one region to another. A man-made transport mode of organic material to natural receiving waters are sewage pipes. Man himself is unable to use all the energy stored in food and his wastes are often discharged into the water without treatment. It is well known that untreated sewage creates a public health danger, being a potential for epidemics of water-borne diseases, such as typhoid fever, and also causes a serious loss of the recreational value of the inland waters (Štirn, 1973; Shuvel, 1986). The present paper, however, is dealing with organic load only since public health problems resulting from sewage require separate attention and a specific strategy of their own.

In addition to the ever-increasing urbanization, industry and development of agriculture and forestry contribute considerably to the organic loads, which pose a hazard for inland waters and fisheries. Accordingly, domestic sewage and organic industrial wastes, as well as wastes from agricultural and forestry products are considered as main sources of organic pollution of African waters. Alabaster (1981) pointed out that agriculture is being further developed in some African countries, leading to an extension of existing industries involved in the processing of plant and animal products and to an increase in the highly oxidizable discharges.

3.1 Municipal Waste Water

According to Dejoux *et al.* (1981), urban pollution is generally organic in origin and is very dependent on the size of the urban development, on the existence of the effluent treatment systems and on the waste disposal habits of the inhabitants.

The principal physical, chemical and biological characteristics of traditional sewage are known. Mixed sewerage systems of modern municipalities, however, do add increasing levels of organic and inorganic material, some of them toxic (e.g. heavy metals), to municipal effluents from small industries. The rise in municipal BOD wastes is related to industrial effects rather than to the great changes in the habits of the population. The increase in the phosphorous compounds transported by wastewater constitutes a major problem. Many African towns have open drain systems, which are flooded during the rainy season, leading to high organic discharge to the receiving waters over short periods of time.

3.2 Organic Industrial Wastes

In most developed countries, industries produce a larger load of organic wastes than municipalities. Wastes with high BOD loads are produced by textile industries, paper and pulp mills, rubber production and chemical industries. Metal industries and mining contribute to a lesser degree to organic loads.

In Africa, food processing is a major industry; plants are mainly located inland, and consequently the discharged wastes create pollution problems in the inland waters (rivers, streams and lakes). Typical examples for such industries are meat processing and dairy plants, sugar refineries, breweries, distilleries and palm-oil industries. The quantities and characteristics of wastes from these sources vary, and the pollution caused by them has to be calculated on a case-by-case basis, especially when the organic load is considered. In general, BOD loads are higher than those of ordinary sewage.

4. PARAMETERS FOR MEASURING ORGANIC POLLUTION

BOD, COD and suspended solids are the traditional parameters for measuring organic pollution. However, parameters such as dissolved oxygen (DO), hydrogen sulphide (H_2S), pH, total dissolved solids (TDS) and nutrients are also important. The nutrients nitrogen (N) and phosphorus (P) have been identified as key factors in the eutrophication of inland water (Vollenweider, 1968). They are measured in their various organic and inorganic forms (e.g. NH_3 , NO_2^- , NO_3^- , PO_4^{3-}).

The most relevant textbook on analytical methods is 'Standard methods for the examination of water and waste water' (APHA/AWWA/WPCF, 1985).

5. CALCULATION OF ORGANIC AND NUTRIENT LOADS

The assessment of nutrient loading and of the relative contribution of the different sources of nutrients to surface waters is of critical importance for the implementation of pollution control measures to prevent or reverse eutrophication.

Analyses provide a precise measurement of nutrient loads but they are very costly and time consuming and they fail to give adequate information regarding the contribution from different sources. The only possible approach to a large-scale evaluation is a theoretical estimate by means of quantification of the various sources, by collecting data on land use, population, agricultural and industrial activities and by applying appropriate and specific coefficients.

This method has been extensively used in developed temperate countries, and suitable coefficient are available. For tropical countries some modifications are necessary and extrapolations would have to be made.

6. SELECTED AFRICAN EXPERIENCES

The two major sources of organic matter and nutrients are domestic discharges and food processing industries. The increase in African population is exponential, especially in towns; the population of Bujumbura, for example, has tripled in twenty years. The populations of Abidjen and Legos have increased by twenty times in forty years. Cairo, according to the last census, has more than 10 million inhabitants. Similar trends can be observed everywhere in Africa.

Despite the fact that in many situations the organic load has not been properly quantified, one should stress the relevance of food processing industry in all African countries in contributing to the BOD load, especially of big rivers. Dajoux (1988) gives the following examples: Wastes from fruit juice production and breweries are discharged to the Niger at Bamako, to the Marahoué in Côte d'Ivoire, to the Logone in Chad, as well as to the Abidjan and Lagos Lagoon and to the coastal lake Nokoué in Benin.

Wastes are seasonally discharged from sugar-cane processing at Ferkessedougou to the Bandama River, at Banforé to the Comoé (Burkina Faso) and to the Sebi-Lundi River in Zimbabwe, from coffee processing at Bouaflé to the Bandama, and to Riva Nyando in Kenya. Palm oil factories, milk processing industries, sisal, etc., are other important sources for wastes with a high BOD.

Alabaster (1981) and Calamari (1985) have reviewed the state of aquatic pollution in Burundi, Cameroon, Côte d'Ivoire, Ghana, Kenya, Mali, Malawi, Nigeria, Sudan, Tanzania and Zambia. Both reviews reported on the research activities and publications in these countries. Some of this research deals with the organic wastes and their effects on the receiving inland waters.

In the following part, selected African experiences are reported, illustrating situations in which water bodies suffer from organic loads and referring to research conducted and effects observed.

6.1 Northern Africa

In North Africa, the delta lakes in Egypt are influenced by organic pollution to various degrees, depending mainly on the discharge rates and the dilution capacity. The depths of these water bodies (Nozha Hydrodrome, Lake Mariout, Lake Edku, Lake Brollus and Lake Manzalah) range from 1 to 1.5 m. Lake Mariout, which was once a highly productive lake, is now considered as the most polluted delta lake, severely affected by domestic sewage from the southern part of Alexandria, by industrial wastes from several factories constructed close to the northern side of the lake and by agricultural runoff. Next in order of pollution is the Nozha Hydrodrome. Because of their considerable size, Lake Edku, Lake Brollus and Lake Manzalah show a pollution gradient from regions further away from the direct effect of discharges to those near the waste outfalls.

A considerable part of the allochthonous organic matter in the form of sewage and the autochthonous organic substances resulting from the subsequent increase in bioproductivity, decomposes, consuming dissolved oxygen and causing deoxygenation of the water. The biota, particularly fish, may be asphyxiated. After depletion of dissolved oxygen, anaerobic decomposition of organic matter continues (the stagnating water turns septic) and decomposition gases are produced. Among them is the toxic hydrogen sulphide, which is recognized by its unpleasant smell. Suspended materials deposit on the bottom and thus blanket it. This affects the spawning of fish and reduces the numbers of bottom fauna, important for the food chain. In Lake Mariout, fisheries have been affected since about 30 years. Some fish species have decreased in number or disappeared. *Tilapia* species, relatively unaffected by pollution, now account for about 80% of the fish production in this lake.

Organic pollution of Lake Mariut and its effects have been widely studied by Sead (1972, 1972e, 1973, 1974, 1980, 1985a), Saad *et al.* (1984), Wehby and Abdel-Mouniem (1979) and Wehby *et al.* (1978). Sediments in different delta lakes were analyzed by Saad (1978, 1979, 1980a, 1980b). Saad (1978a, 1985b) also describes the dissolved organic matter content of Lake Edku. Changes in the blood of fish due to pollution were found by Saad *et al.* (1973).

The Nile in Egypt, being the lower part of the river, contains considerable concentrations of organic matter resulting from allochthonous supply (mainly domestic wastes) and eutrochthonous production (Saad, 1980c; Saad and Abbas, 1985). Levels of organic matter in Aswan Lake are not so high as to cause pollution in this second largest man-made lake in the world. Obviously, part of the organic matter in this lake originates from the inflowing Nile water, which receives this matter mainly from discharges of the countries upstream.

The Lake of Tunis suffers much from organic pollution (Štirn, 1967, 1968, 1972, 1973). In certain areas dissolved oxygen is depleted and hydrogen sulphide is produced as a result of anaerobic decomposition of organic matter; the unpleasant odour of this gas can be smelled near these septic zones.

6.2 West and Central Africa

Of the total population of Côte d'Ivoire, estimated at 7.9 million in mid 1979, about 1.5 million are concentrated in and around Abidjan. Of these, only about 350 000 are serviced by the sewage system discharging into Ebrié Lagoon. Pagès and Citeau (1978) analyzed the concentrations of faecal coliforms in the central part of the lagoon over a year cycle and found several heavily contaminated areas. Environmental degradation is also reflected in low concentrations or even absence of oxygen at the bottom, i.e. in Coccody, Marcory and Biatry bays and in subsequent changes in the benthos fauna. In fact the benthic populations in the bays are now dominated by certain species of oligochaetes, considered as indicators of heavy pollution. The area suffers also from industrial discharges from light industry.

In Ghana, Biney (1982) classified all areas of the country according to the BOD level into three categories: "unpolluted and recovering from pollution" (< 4 mg/l), "doubtful and poor quality" (4-12 mg/l) and "grossly polluted" (> 12 mg/l). Of the 16 lagoons investigated by Biney (1982), 12 were found polluted in varying degrees; grossly polluted are Korla (Accra) and Chemu (near Tema), serving as receptacles of industrial and domestic wastes. Lake Berekese, a man-made lake in the Ashanti region of Ghana which is used as a water supply reservoir, has been extensively studied (Amuzu, 1973, 1975).

In Mali most of the activities depend on the Niger and its tributaries. According to the information obtained by Calamari (1985), pollution problems are not too critical and could easily be managed; most of the wastes consist of oxidizable matter.

In Cameroon, several mass mortalities were recorded in partially-managed river areas near Nafussam, caused by oxygen depletion due to the large organic load (Calamari, 1985).

Domestic and industrial organic loads

Except for a few regions, in Nigeria urban areas do not have any central sewerage system or sanitary excreta disposal system. The waste water from most parts of more than 186 urban centres is carried in open drains into streams and rivers, a characteristic feature of many developing countries (Sridhar *et al.*, 1981). According to Calamari (1985), analytical data on the lagoon of Lagos (the largest town in Nigeria) do not exist. However, this lagoon, once very productive in fish, is now considered as a bad place for fishing (Adeyanju, 1979). Ekundayo (1977) reported that the eutrophication of Lagos Lagoon was due primarily to extensive pollution by large quantities of industrial and domestic wastes. In Ibadan, the chemical and microbiological characteristics of the waste water flowing in open drains has been investigated by Sridhar *et al.* (1981). These open drains, carrying various pollutants, contribute to the pollution of streams, since they travel short distances and consequently offer only limited self-purification of the waste water. In densely populated areas the waste water showed higher values of turbidity, total and suspended solids, oxidizable organic matter, BOD and ammonia nitrogen, with negligible concentrations of dissolved oxygen. The waste water finally enters three major streams, which could be considered open sewers, with water colour ranging from greyish to black, devoid of fish. The water quality in one of these streams can be compared to that of partly treated waste water, turbid and with considerable amounts of total and suspended solids, oxidizable organic matter, BOD and ammonia nitrogen (Sridhar *et al.*, 1981).

The effects of sewage pollution on the distribution and abundance of some organisms, including insects, algae and crustaceans have been studied (Oladimeji and Wade, 1984). In the anaerobic zones of the study area only a few tolerant invertebrate species such as *Eristalis* and *Psychoda* were found. The number of organisms increased as conditions such as dissolved oxygen concentration and electrical conductivity improved. Fishes such as *Epiplatys* sp. and *Barilius niloticus* were abundant in areas with high dissolved oxygen concentrations.

According to Beecroft *et al.* (1987) and Awanda (1987), the bulk of the organic load discharged into the Kaduna River comes from the breweries (NBL and IBB). Waste water discharge from these sources originates from liquors extracted from grains and yeast and have the characteristic smell of malt. They are slightly acidic (pH 5-6), with high particulate and soluble organic content. Effluents from the textile industries have been shown to contain fibres, toxic organic chemicals and heavy metals. The phytoplankton density is lower in points of the Kaduna receiving heavy loads of organic pollutants. The lower number of species of flora and fauna below the Kakuri drain, which carries the effluents from the textile mills and breweries to the river, are attributable to organic pollution. Awanda (1987) noted that the higher density of certain dominant groups of chironomid (midge) larvae and nematodes at some of these heavily polluted points may be an indication that only these species, tolerant of low dissolved concentrations, are able to survive.

6.3 Eastern Africa

East African inland water systems have undergone successive changes since the mid-fifties due to intensive selective fisheries, modification of the drainage area, invasion by introduced species and the increasing physico-chemical changes in the environment. In Kenya, organic pollution and eutrophication of inland waters is to be attributed to the increase in population, urban and industrial activities and agricultural production (Kallquist

and Maadows, 1977; Meadows, 1980; Alabaster, 1981; Ochumba, 1985). Indicative of the deterioration of water quality in Lake Victoria are algal blooms and fish mortality (Ochumba, 1987; Ochumba and Kibaera, 1989) and species reduction (Okemwa, 1984; Barel *et al.*, 1985). The rift valley lakes (Baringo, Turkana, Naivasha, Nakuru and Elementaita) are threatened by receding lake levels due to drought and by industrial and riparian agriculture (Maadows, 1978; Harper, 1984).

The potential problems of organic pollution in Tanzania's inland waters are described by Ngoile *et al.* (1978), Alkbrant (1979), and McAuslan (1980); main threats to Lake Tanganyika are riparian agriculture and oil prospecting. In Burundi, the main concerns are the discharge of sewage and industrial wastes to Lake Tanganyika (REGIDESO, 1980) and agricultural inputs to the Rizi River (Autrique, 1977). Internal overturns in the rift valley lakes in Uganda and Ethiopia have been associated with fish kills and algal blooms (Burgis, 1978; Belay and Wood, 1984) due to nutrient enrichment and oxygen depletion. Magasa (1978) concluded that organic pollution in Malawi is centred around Blantyre City and the Shire River, which receives agriculture-based wastes. In Zambia, Mumba *et al.* (1978) have indicated that water pollution is mainly a problem with the Kafue River due to industrial and urban development; fish kills in the river (Kaoma and Salter, 1979) were due to excessive levels of nitrogen compounds.

6.4 Southern Africa

Marshall reported limnological data for 33 Zimbabwean lakes and used them to predict their fish yields. Except for eutrophic lakes such as the Mcllwaine, phosphorus was found to be the major limiting nutrient.

Since the early sixties, several algal blooms occurred in Lake Mcllwaine due to nutrient enrichment through urban discharges from the town of Harare. Measures had been taken to reduce eutrophication, e.g. some of the effluents were used to fertilize the farmland around the town, particularly during the rainy season. However, such measures were considered insufficient (Wells, 1975).

A review of the more recent situation of this lake is given by Thornton (1981) with a self explanatory title, 'Lake Mcllwaine: an ecological disaster averted'. He describes the recovery of the lake after severe measures had been taken to reduce the total load of nutrients. In the same area, Harare region, Thornton and Nduku (1982) showed that drainage waters from heavily urbanized areas had nutrient contents two to twenty times higher than waters from forest and savannah areas.

7. CONTROL OF ORGANIC POLLUTION

The above review of effects of organic pollution on inland waters evidences the need for control of this type of pollution, which is best achieved by control at its source. As many sources of organic pollution are at the same time generating other pollutants, their control resolves a number of pollution problems.

Although organic matter is the most important source of African inland water pollution, discharges of limited quantities of organic pollutants are unlikely to have harmful

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effects on large lakes or even small water bodies. In fact, each environment has the capacity to accommodate limited, quantifiable loads of pollutants, defined as Environmental Capacity (GESAMP, 1986). Furthermore, large amounts of organic wastes can be controlled by the introduction of more economical technologies which may even facilitate constructive use of the nutrients. However, not only primary consequences but also processes of secondary organic pollution have to be kept under control as they may lead to irreversible damage of the ecosystems.

Legal, administrative and technical measures are necessary to reduce or eliminate the undesirable effects of organic loads, a.g. unacceptable physical, chemical and biological changes in the receiving inland waters. Consequently, multi-disciplinary team work is needed for water pollution control.

At national level control of aquatic pollution is achieved by:

- (i) formulation of national policy for pollution control;
- (ii) enactment of appropriate legislation, and
- (iii) establishment of appropriate institutional arrangements (administrative and technical) for monitoring, implementing and regulating pollution control.

Alabaster (1981) and Calamari (1985) reviewed the existing situation in eleven countries in Eastern, Western and Central Africa. According to Alabaster (1981), water pollution control legislation has evolved rapidly in several countries but is still under review in others. In a few cases environmental legislation is already being used effectively for pollution control.

It is hoped that each African country will achieve its own environmental legislation in the near future, taking into consideration the experience of developed countries in order to avoid the mistakes made there. It is important that such legislation includes requirements for environmental impact assessment, a process for incorporating environmental considerations into all development activities already at the planning stage. Also, legislation must provide mechanisms for the enforcement of aquatic pollution control laws, ideally with the support of local and provincial offices.

Monitoring systems have to be established to check on the health of the aquatic environments and the effects of large loads of organic wastes on the biota, especially the commercially important species. In African countries, the steps indicated below are proposed for a monitoring programme.

A survey should be carried out to identify the principal pollution sources. According to Calamari (1985), a register of point sources has been completed or is at an advance stage of preparation in the five countries he visited in West and Central Africa. For each water body, calculations are made of the BOD and other water quality characteristics of the organic wastes, discharged untreated or from municipal and industrial treatment plants. The organic loads of the receiving waters should also be investigated, taking into consideration seasonal changes of runoff and biological activities.

A map of the receiving waters based on the survey is then prepared, showing for each water body the organic pollution load in BOD and its different sources, as well as the number of treatment plants for domestic and industrial wastes. On the basis of this map, certain areas in which organic pollution is serious can be selected. Special attention should be given to these areas, and the different compartments (water, sediments and organisms) should be monitored over a suitable period (one to two years).

Biological monitoring uses living organisms as sensors for environmental quality; species composition and diversity, as well as population density, normally decrease with lowering of the water quality. Methodology comprises sample collection and processing, identification and counting of aquatic organisms as well as biomass measurements. Since sample collection and observations are performed in the field and analyses are carried out in the laboratory, research stations are needed, preferably near the polluted areas.

The results obtained from the selected heavily polluted areas are useful for the design of a continuous monitoring programme, which could cover all polluted inland waters in a country. Such large-scale monitoring activities necessitate a number of suitable laboratories in well-equipped research institutes and fishery departments, as well as a sufficient number of trained technical and scientific personnel. In some African countries water pollution laboratories do exist, but with insufficient means. Therefore, improvement of the equipment and structure of the existing laboratories, as well as the establishment of new laboratories, is highly recommended.

8. CONCLUSIONS

- Pollution from organic matter and nutrients is of considerable importance in African inland waters and fisheries. Remedial actions should be undertaken.
- A lot of information is still missing, and specific research programmes at national and regional level are needed; this entails the need for a network of adequately equipped laboratories.
- Exchange of data and experience between African countries concerning organic pollution and its control is necessary, in particular on self-purification processes under African climatic conditions and on waste treatment processes for domestic and industrial organic wastes appropriate for Africa.
- An increase in the number of experts on the subject and intensification of training and education are called for.

REVIEW OF HEAVY METALS

by

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1. INTRODUCTION

In natural aquatic ecosystems, metals occur in low concentrations, normally at the nanogram to microgram per litre level. In recent times, however, the occurrence of metal contaminants' especially the heavy metals in excess of natural loads, has become a problem of increasing concern. This situation has arisen as a result of the rapid growth of population, increased urbanisation, expansion of industrial activities, exploration and exploitation of natural resources, extension of irrigation and other modern agricultural practices as well as the lack of environmental regulations.

At the global level the scientific community has investigated some of these problems and the results have been published in several reviews and books (Nriagu, 1989; Förstner and Wittmann, 1981; Salomons and Förstner, 1984). Most of the present introductory material is based on these sources.

Unlike other pollutants like petroleum hydrocarbons and litter which may visibly build up in the environment, trace metals may accumulate, unnoticed, to toxic levels. Thus problems associated with trace metal contamination were first highlighted in the industrially advanced countries because of their larger industrial discharges and especially by incidents of mercury and cadmium pollution in Sweden and Japan (Kurland *et al.*, 1960; Nitta, 1972; Goldberg, 1976). In spite of the relatively low level of industrial activity in less developed regions such as Africa, there is nevertheless growing awareness of the need for rational management of aquatic resources including control of waste discharges into the environment. This becomes even more important in view of the expected increases in industrial and urban activities in all parts of the continent.

Existing information on various environmental problems has been reviewed by Dejoux (1988) in a monograph of pollution in African inland waters and by Phillips (1991) on a worldwide basis on tropical marine ecosystems. These publications showed that the existing information on Africa is scattered and scarce, and therefore demonstrated the need for a more precise and specific review of the occurrence of trace heavy metals in various aquatic environmental compartments in the continent.

For effective water pollution control and management there is a need for a clear understanding of the inputs (loads), distribution and fate of contaminants, including trace metals from land-based sources into aquatic ecosystems. In particular, the quantities and qualities need to be considered together with the distribution pathways and fate and the effects on biota.

The need to make an assessment of the level of heavy metal contamination in the African environment has led to the initiation of several pollution monitoring programmes and research work in various universities and scientific institutions in the region. The most relevant programmes are the Mediterranean pollution monitoring programme (MEDPOL) covering also North Africa, the West and Central Africa marine pollution and research programme (WACAF 2) and the Eastern Africa marine pollution and research programme (EAF/6).

During the last decade, there have also been considerable improvements in the sampling and analytical techniques for trace metals. These, coupled with international intercomparison exercises, have facilitated the generation of more reliable data. The present paper thus attempts to compile and analyze the available information on the occurrence of trace metals in both freshwater and marine ecosystems of Africa as a contribution towards the formulation of rational management policies for aquatic resources in the continent.

The decision to review freshwater and marine data jointly is a result of the need to have a holistic approach that could influence future control strategies.

2. SOURCES OF TRACE METALS

Trace metals enter the aquatic environment from both natural and anthropogenic sources. Entry may be as a result of direct discharges into both freshwater and marine ecosystems or through indirect routes such as dry and wet deposition and land runoff. Important natural sources are volcanic activity, continental weathering and forest fires. The contribution from volcanoes may occur as large but sporadic emissions due to explosive volcanic activity or as other low continuous emissions, including geothermal activity and magma degassing (Zoller, 1984). The major sources of atmospheric mercury, for example, are land and ocean degassing (GESAMP, 1988). In view of the toxic nature of the trace heavy metals, the knowledge of their sources and fate in the environment is important.

The anthropogenic sources include:

- (i) Mining effluents
- (ii) Industrial effluents
- (iii) Domestic effluents and urban storm-water runoff
- (iv) Leaching of metals from garbage and solid waste dump
- (v) Metal inputs from rural areas, e.g. metals contained in pesticides
- (vi) Atmospheric sources, e.g. burning of fossil fuels, incineration of wastes and industrial emissions
- (vii) Petroleum industry activities.

Table I presents examples of potential sources for metals in the environment.

In some African countries, mining activities are important sources of heavy metal input to the environment, for example mercury in Algeria, arsenic in Namibia and South Africa, tin in Nigeria and Zaire, and copper in Zambia.

Table I
Industrial and agricultural source for metals in the environment

Use	Metal
Batteries and other electricals	Cd, Hg, Pb, Zn, Mn, Ni,
Pigments and paints	Ti, Cd, Hg, Pb, Zn, Mn, Sn, Cr, Al, As, Cu, Fe
Alloys and solders	Cd, As, Pb, Zn, Mn, Sn, Ni, Cu
Biocides (pesticides, herbicides, preservations)	As, Hg, Pb, Cu, Sn, Zn, Mn
Catalysts	Ni, Hg, Pb, Cu, Sn
Glass	As, Sn, Mn
Fertilizers	Cd, Hg, Pb, Al, As, Cr, Cu, Mn, Ni, Zn
Plastics	Cd, Sn, Pb
Dental and cosmetics	Sn, Hg
Textile	Cr, Fe, Al
Refineries	Ni, V, Pb, Fe, Mn, Zn
Fuel	Ni, Hg, Cu, Fe, Mn, Pb, Cd

For most trace metals, anthropogenic emissions are more than or equal to natural emissions. The combustion of leaded petrol in automobiles, for instance, is responsible for the widespread distribution of lead in the world. For mercury, however, several reports (Hutchinson and Meema, 1987; GESAMP, 1988) suggest that natural emissions are quantitatively more important than anthropogenic sources.

From the above considerations the compilation of an inventory of the sources and the quantification of the heavy metal loads appear to be important tasks to be accomplished. Obviously, this exercise should be carried out on a country-by-country basis, with the ultimate goal of a regional and continental overview of the problem.

Metal concentrations in industrial effluents and landfill leachate in African countries are shown in Table II.

3. DISTRIBUTION PATHWAYS AND FATE OF HEAVY METALS IN THE AQUATIC ENVIRONMENT

Once in the aquatic environment, metals are partitioned among the various aquatic environmental compartments (water, suspended solids, sediments and biota). The metals in the aquatic environment may occur in dissolved, particulate and complexed form.

The main processes governing distribution and partition are dilution, advection, dispersion, sedimentation, and adsorption/desorption. Nonetheless, some chemical processes could also occur. Thus speciation under the various soluble forms is regulated by the instability constants of the various complexes and by the physico-chemical properties of the water (pH, dissolved ions, Eh and temperature).

Table II
Mean metal concentrations in some industrial effluents and landfill leachates ($\mu\text{g/ml}$)

Location	Hg	Cd	Pb	Cu	Zn	Mn	Fe	Ni	Co	Reference
GHANA Textile factory effluents			0.65	2.75	0.50		0.31			Siney, 1991a
Gold mine effluents	0.06		1.79	8.91	1.16		9.74			Siney, 1991a
Mine tailing leachates	0.06		2.68	9.32	1.16		14.9			Siney, 1991a
Landfill leachates	<0.01		0.08	0.19	0.49		12.3			Environmental Management Associates, pers. comm.
NIGERIA Textile factory effluents		<0.10	<0.10	0.12	<0.05	0.83	0.50	<0.10	<0.10	Osibanjo, 1991
Soft drinks factory effluents		<0.10	0.02	<0.10	0.05	0.40	2.40	0.02	<0.10	Osibanjo, 1991
Steel plant effluents		0.10		0.70	2.3			0.90	0.90	Nwagu et al., 1987
Oil refinery effluents		0.05	0.20	0.14	0.25		1.45			Kakulu and Osibanjo, 1991;
Landfill leachates (fresh)		0.10	0.10	0.50		13.5	87.2	2.7	1.8	Osibanjo et al., 1988
Landfill leachates (aged)		0.10		0.50		3.8	31.2	2.0	2.6	Adeleye, 1990
KENYA Landfill leachates					13.2		399			Sryceson et al., 1990
TANZANIA Battery factory effluents	2.65									Semu et al., 1986

Adsorption could be the first step in the ultimate removal of metals from water. In the course of distribution, permanent or temporary storage of metals takes place in the sediments of both freshwater and marine environments. Microbial activity and redox processes may change the properties of sediments and affect the composition of interstitial water. As a result, iron and manganese oxides may be converted to carbonates or sulphides, leading to a decrease in the adsorption capacity of the sediments. Reworking of the sediments by organisms will also bring sediments to the surface, where a significant fraction of the metal will be released.

Many transformations of heavy metals in aquatic environments occur as biochemically mediated reduction, methylation, demethylation and oxidation of single metal species. Redox reactions may also facilitate some transformations. The biochemical processes are carried out by microorganisms and algae. According to Jernelöv (1975), methylation of mercury takes place when microorganisms, while consuming organic substances, happen to come into contact with mercury ions. This may also be true for As, Sn and Pb.

Heavy metals are taken up by both fauna and flora. This uptake could provoke an increase in the concentration of the metal in the organism; if the excretion phase is slow, this can lead to the bioaccumulation phenomenon. A few metals such as mercury have been shown to undergo biomagnification through the food chain.

4. EFFECTS OF AND QUALITY CRITERIA FOR METALS

Some heavy metals such as Zn, Cu, Mn and Fe are essential for the growth and well-being of living organisms including man. However, they are likely to show toxic effects when organisms are exposed to levels higher than normally required. Other elements such as Pb, Hg and Cd are not essential for metabolic activities and exhibit toxic properties.

Metal contamination of the aquatic environment may lead to deleterious effects from localised inputs which may be acutely or chronically toxic to aquatic life within the affected area. Most published data on the effects of metals on aquatic organisms, however, report adverse effects at concentrations higher than usually found in the environment (GESAMP, 1985; 1988).

Metals may be taken up in the inorganic or organic form. For some elements, such as arsenic and copper, the inorganic form is the most toxic. For others, such as Hg, Sn and Pb, the organic forms are the most toxic. At low concentrations many heavy metals, including Hg, Cd, Pb, As and Cu, inhibit photosynthesis and phytoplankton growth. Effects at higher trophic levels include delayed embryonic development, malformation and reduced growth of adults of fish, molluscs and crustaceans.

In the last two decades, many investigations have been conducted on the toxicity of metals the results of which have formed the basis for the formulation of water quality criteria for aquatic life by several international and national organizations.

For example, the European Inland Fisheries Advisory Commission (EIFAC) of the Food and Agriculture Organization (FAO) gave the following definition for water quality criteria to protect fisheries:

"Water quality criteria for freshwater fish should ideally permit all stages in the life cycle to be successfully completed, and in addition, should not produce conditions in a river water which would either taint the flesh of the fish or cause them to avoid a stretch of river where they would otherwise be present, or give rise to accumulation of deleterious substances in fish to such a degree that they are potentially harmful when consumed. Indirect factors like those affecting fish-food organisms must also be considered, should they prove to be important". A number of water quality criteria have been produced by EIFAC (Alabaster and Lloyd, 1982; Howells, 1994).

The major routes of heavy metal uptake by man are food, water and air. For example, aquatic fauna, especially fish, are the most important source of mercury and arsenic for human beings.

Many publications exist on the effects of heavy metals in humans, and reviews have also been prepared on these subjects by the International Programme on Chemical Safety of the World Health Organization (IPCS/WHO) and disseminated through the Environmental Health Criteria publication series.

The WHO has also produced water quality criteria for drinking water for several chemicals including most of the heavy metals (WHO, 1984) while FAO has made a compilation of legal limits for hazardous substances in fish and fishery products with particular reference to heavy metals (Neuen, 1983; FAO, 1989).

5. METHODS OF ANALYSIS

Several methods have been used to determine trace elements in environmental matrices. In early studies, gravimetric, volumetric and colorimetric techniques were employed. The more common colorimetric method involved formation of soluble metal complexes, chelates, with such organic compounds as dithizone, o-phenanthroline and ammonium pyrrolidine dithiocarbamate (APDC). Modern methods such as anodic stripping voltammetry (ASV) and the use of ion-selective electrodes (ISE) are based on electrochemical principles.

Other methods employ nuclear related techniques. These include proton-induced X-ray emission (PIXE), instrumental neutron activation analysis (INAA), X-ray fluorescence (XRF) and inductively coupled plasma mass spectrometry (ICP-MS). Most of these methods are however very expensive, and only a few recent studies in Africa (Kakulu *et al.*, 1987; Akoto Bamford *et al.*, 1990; Onwumere and Oladimeji, 1990) have reported using them.

Also in Africa, by far the most common method for the determination of heavy metals is atomic absorption spectrophotometry (AAS). It has the advantage of speed, sensitivity, simplicity and ability to analyze complex mixtures without prior separation. For most of the heavy metals the basic technique involves flame atomization, while for some

of them at very low concentrations the graphite-furnace technique involving electrothermal atomization is used. Vapour-generation methods may be used for a few metals such as As, Se, and Sb, whereas mercury is analyzed by the cold vapour technique.

6. SELECTED AFRICAN EXPERIENCES

In the following section, selected African experiences have been summarized. These refer to research conducted on distribution of metals in various environmental compartments and illustrate situations in which water bodies are influenced by metal loads.

6.1 Northern Africa

Heavy metals and pesticides in Northern African waters were studied more recently than other chemical parameters. The compartments water and sediments, as well as selected biota of inland water bodies and coastal marine areas, have been investigated. Of the different matrices, sediments have been more analyzed because they can present a clearer indication of metal inputs and accumulation in aquatic environments.

Studies of heavy metals in Northern Africa have been concentrating on Egyptian inland waters and coastal zones, particularly on the river Nile and its two branches (Rosetta and Damietta), as well as on the delta lagoons. However, many studies have been conducted within the framework of the 1975 Action Plan for the protection of the Mediterranean and have therefore focused on the coastal zones. Advanced investigations on the dynamics and speciations of trace metals are also being conducted in different Egyptian inland and coastal marine waters.

Bernhard and Renzoni (1977) differentiated between natural and anthropogenic sources of mercury pollution in the Mediterranean by reviewing concentrations in pelagic fishes and benthic organisms, as well as sediments.

Tomé *et al.* (1981) investigated the distribution of adsorbed metals on the fine fraction of the sediments of the western part of the Nile continental shelf (offshore, near shore and river environments). The authors concluded that abundance of metals occurred in the order $Fe > Mn > Zn > Cu$, and their distribution was identical with the pattern of sediment transport. High concentrations of metals were recorded at certain localities and some of them, reaching potentially toxic levels for aquatic organisms, were attributed to contaminated drainage waters. The occurrence of some heavy metals in the sediments of Abu-Kir Bay of the Mediterranean Sea was studied by Saad *et al.* (1981b). The metals (Cu, Cd, Zn, Fe and Mn) showed a pattern of distribution similar to that of the mud and organic matter content of the sediments. The effects of industrial effluents were found to be restricted to sediments in the vicinity of their discharge.

Studies on the surface sediments of El-Mex region of the Mediterranean in front of Alexandria (Saad *et al.*, 1981) revealed two zones, one of which showed high concentrations of Mn, Cu, Cd, Zn and Fe, as a result of discharges of industrial effluents. Their findings also suggested incorporation of similar proportions of Fe and Mn into the sediments and the co-precipitation of Cu and Zn by iron oxides.

The occurrence and distribution of metals in the water of the heavily polluted Lake Mariut in Egypt, and their accumulation in the different parts of a common fish (*Tilapia* sp.) in this lake were investigated by Saad *et al.* (1981a). Variations in the concentrations of metals (Zn, Cu, Fe, Mn and Cd) in the lake water were mostly attributed to variations in the discharge rates of the dumped wastes. The levels of these metals in fish were much higher than those in water.

The seasonal distribution of dissolved and particulate heavy metals in the water column of the Damietta branch of the river Nile was studied by Fahmy (1981). El-Rayis and Saad (1985) estimated the contribution of trace metals from the river Nile to the eastern Mediterranean by determining the concentrations of dissolved metals in the surface and subsurface water along the Rosetta branch. The relative abundance was $Zn > Fe > Cu > Mn > Cd$.

Saad and Fahmy (1985) studied the occurrence of trace metals in surficial sediments from the Damietta estuary of the Nile and concluded that the eastern side of the estuary was exposed to more pollution than the western side. Also, areas of maximum averages of Cu, Zn and Cd coincided with the discharge sites of sewage wastes.

Metal enrichment in surficial sediments of three shallow Nile delta lakes (Lake Mariut, Nozha Hydrodrome and Lake Manzalah) was evaluated using Fe/metal ratios by Saad *et al.* (1985). A further study on heavy metals in water, sediments and fish of Lake Mariut was made by Saad (1985). The results revealed the existence of a direct relationship between the levels of metals in the lake water and in the different fish parts. The metal concentrations in the lake water were markedly lower than those in fish and the levels, excluding cadmium, in the lake sediments were considerably higher than those in fish. Analyses of sediments, aquatic plants and water from the river Nile and its branches at selected sites characterized by heavy industrialization and dense populations (Fayed and Abd El-Shafy, 1985) showed higher concentration factors in sediments than in plants.

El-Rayis and Saad (1986) studied the levels of heavy metals in a big land-based source of contaminated drainage water contributing six million m³/day to the coastal Mediterranean region in front of Alexandria. Another study by El-Rayis and Saad (1986a) divided Lake Mariut into two zones, septic and non-septic, after metal analysis of suspended matter and water. According to El-Rayis *et al.* (1986), copper and zinc were found to be concentrated in the sandy sediments of the shallow sides of the Eastern Harbour of Alexandria, whereas iron and manganese occurred in the deeper sediments.

Saad (1987) studied heavy metals in the Nozha Hydrodrome by analyzing water, sediments and different parts of *Tilapia* sp. to gain information on the levels of these metals and their possible variations in relation to pollution effects from discharges of polluted Nile water into the lake. The results suggested a direct relationship between the concentrations in water and in fish. They also illustrated the ability of fish to absorb high levels of heavy metals and the ability of lake sediments to accumulate these metals. El Rafei *et al.* (1987) quantified the levels of trace metals in waste waters discharged into the river Nile from some industries near Cairo. El-Nabawi *et al.* (1987) determined metal concentrations in fish from Lake Mariut, Lake Edku and Abu-Kir Bay and found the highest levels in *Sphyræna sphyræna* from this bay. Moharram *et al.* (1987) estimated the levels of total, organic, inorganic mercury, total selenium and the interaction between both

metals in *Mugil cephalus*. A strong correlation was reported between fish length and each of these variables.

Data on trace metals in the Red Sea are scanty. Saad and Kandeel (1988) investigated the distribution of Cu, Fe and Mn in the coastal Red Sea waters in front of Al-Ghardaqa. The different patterns of seasonal distribution and the irregular variations of these metals were discussed.

Heavy metal pollution in Lake Mariut has been further investigated by El-Rayis and Saad (1990), based on the distribution of Cu, Zn, Fe and Mn in water, suspended matter and sediments. The contribution of metals from this lagoon to the Mediterranean Sea via Umum Drain (contaminated land-based source) was also estimated.

6.2 West and Central Africa

Studies on the occurrence and distribution of metals in Nigeria have been conducted on all the major environmental matrices (water, sediment, fauna and flora) but again with more emphasis on sediments.

Statistical treatment of the results of metal analyses of 176 stream sediment samples from the Ife-Ilesha area (1800 km²) of southern Nigeria (Ajayi, 1981) showed that all the elements have density distribution close to natural background levels. Ojo (1988) also used various statistical methods for the interpretation of the geochemical data obtained from analyses of Cu, Pb, Zn, Co, Ni, Fe, Mg, Mn and Ca in 374 stream sediment samples collected over an area of 700 km² within the upper Benue Trough (Nigeria) and concluded that these elements exhibit various patterns of association depending on their nature and prevailing environmental conditions. Other studies in the area (Kakulu and Osibanjo, 1988, 1992) revealed elevated levels of Pb, Cr, Ni, V and Zn in Port Harcourt and Warri sediments which suggest that effluents from petroleum refineries located in these cities have contributed significantly to the heavy metal pollution of the respective aquatic ecosystems.

Okoye *et al.* (1991) reported anthropogenic heavy metal enrichment of Cd, Co, Cu, Cr, Fe, Mn, Ni, Pb and Zn in the Lagos lagoon and implicated land based urban and industrial wastes sources.

Pollution studies on 26 rivers in some southern and northern states of Nigeria (Ajayi and Osibanjo, 1981), on rivers in the Niger Delta (Kakulu and Osibanjo, 1992), on the cocoa growing area of Ondo State in South West Nigeria (Ogunlowo, 1991) and the Lagos waters (Okoye, 1991a) showed that, with the exception of iron, the concentrations of most trace metals in the surface waters are generally lower than the global average levels for surface waters and the international drinking water standards.

Ndiokwere and Guinn (1983) determined As, Cd, Cr, Hg, Mn, Mo, Ni, Se and Sb in two Nigerian rivers and two harbours and attributed high metal concentrations to local pollution sources. In their studies of streams and lakes around Ibadan, Mombeshora *et al.* (1983) reported much higher levels of lead in sediments than in water. The highest levels of lead coincided with areas of high traffic density.

Analyses of sediments and fish from the Niger delta area of Nigeria (Kakulu and Osibanjo, 1986) revealed that the area was relatively unpolluted with mercury compared to some European areas (Mediterranean, Baltic Sea and North-East Atlantic). Reports from the same area (Kakulu *et al.*, 1987a) indicated that the levels of Cd, Cu, Fe, Mn, Pb, and Zn were higher in shellfish than in finfish. With the exception of the lead levels in some shellfish, levels of these metals were generally lower than the WHO recommended limits in foods. Concern about the high levels of lead in Legos lagoon fish has also been expressed (Okoye, 1991).

Other Nigerian studies include that of Sridhar (1988) who analyzed the aquatic plant *Pistia stratiotes* and showed that the shoot system accumulated more K, Ca, and Mg, whereas the roots accumulated significantly more Cd, Cr, Co, Fe, Pb, Hg, Ni, and Zn.

Onwumere and Oladimeji (1990) reported that *Oreochromis nilotica* exposed to treated petroleum refinery effluents accumulated trace metals in the order Pb > Cu > Zn > Mn > Cr > Ni > Cd.

In other parts of West Africa, the concentrations of major and minor ions, including Cu, Mn and Fe in river Jong, Sierra Leone, was determined by Wright (1982), who found a clear relationship between metal concentrations and seasonal variations in rainfall.

In Ghana, one of the earliest studies (Amese, 1975) examined various matrices, including drinking water, from the Obuasi gold mining area and found that arsenic concentrations occurred above normal values. A more recent study (Akoto Bamford *et al.*, 1990) in which heavy metal pollution from gold mining activities was assessed by analyzing gold ore, tailings, sediments and water for Cr, Mn, Fe, Cu, Zn, As, Pb, Rb, Sr, Y, Zr and Nb, revealed the presence of all the elements in sediments within a concentration range of 0.08 to 49 000 µg/g, whereas only iron and zinc were detected in water at levels of 0.08-2.4 (µg/ml).

Total mercury concentrations in commercial fish from different coastal sites of Ghana have been determined by Ntow and Khwaja (1989) who concluded that all values were well below the 0.5 µg/g action level adopted in many countries. Biney and Beeko (1991) conducted a survey of metals in fish and sediments from the River Wiwi in Kumasi and found a positive correlation between mercury concentration and body weight of fish. They also reported higher levels of cadmium and mercury in fish than in sediment. Studies on the distribution of Hg, Cd, Pb, Cu, Zn and Fe in water, finfish and shellfish, macrophytes and sediments from Kpong headpond and lower Volta river (Biney, 1991) showed the highest concentration of iron and lead in sediments and of manganese and cadmium in macrophytes. Finfish had the lowest concentrations of the metals, except for lead.

Pelig Ba *et al.* (1991) assessed the level of contamination of drinkable ground-water from the Accra plains and upper regions of Ghana and found that in some areas Pb, Cr and Fe concentrations exceeded the WHO guideline limits for drinking water.

In Côte d'Ivoire Marchand and Martin (1985) and Kouadio and Trefry (1987) have studied sediments of the Ebrié Lagoon and reported metal concentrations in excess of background levels, this was attributed to the disposal of untreated sewage and industrial effluents.

A comparative study by Métongo (1991) of Cd, Cu, Hg and Zn in samples of oysters (*Crassostrea gasar*) from urban and rural lagoon areas of Côte d'Ivoire revealed higher but background levels of the metals in the urban area. Likewise, other studies of heavy metals in *Callinectes amnicola* (Métongo and Sankaré, 1990) and in *Thunnus albacares* (Métongo and Kouamenen, 1991) gave concentrations lower than internationally acceptable limits for seafood.

In Senegal, analyses by Gras and Mondain (1978) of fish and crustaceans from coastal waters revealed lower mercury concentrations than the generally acceptable limits (0.5 µg/g), except in swordfish and shers weighing more than 5 kg.

Other studies on the occurrence of trace metals have been conducted as part of the Joint FAO/IOC/WHO/IAEA/UNEP Project on monitoring of pollution in the marine environment of the West and Central African region. Within this framework, concentrations in marine biota have been reported for Cameroon (Mbome *et al.*, 1985; Mbome, 1988), Ghana (Biney, 1985; Biney and Ameyibor, 1989) Côte d'Ivoire (Métongo, 1985, 1988) and Senegal (Be *et al.*, 1985; Ba, 1988). On the basis of these studies, Portmenn *et al.* (1989) reviewed the levels of contaminants in the marine environment of the region and concluded that there was little input of mercury and other metals into the coastal zone from land.

6.3 Eastern Africa

Early studies in this region focused on Lake Nakuru in Kenya, one of a number of soda lakes in the Great Rift Valley which was made a national park in 1986 because of its world-famous flamingo population.

In an attempt to produce baseline information for monitoring pollution, Koeman *et al.* (1972) determined As, Sb, Cu, Zn, Cd and Hg in muscle, liver and kidney of birds and fish. They concluded that the metal concentrations did not constitute a hazard to the biota of Lake Nakuru. Six years later, Greichus *et al.* (1978a) studied water sediment, benthos and fish, and reported slightly elevated concentrations as compared to values found by Koeman *et al.* (1972).

The effect of copper ions on the photosynthetic oxygen production of phytoplankton, on the growth rate of blue-green algae (*Spirulina platensis*) and on populations of rotifers (*Brachionus* sp.) in water from Lake Nakuru was experimentally investigated by Kallqvist and Meadows (1978). The rotifers were less sensitive to copper than algae. Other studies by Lewin (1976) showed that Lake Nakuru water contained 0.08 mg Cu/l mainly from pesticide containing run-off from the surrounding agricultural lands. This value was thus higher than the critical value of 0.02 mg Cu/l, which may significantly reduce algal growth (Kallqvist and Meadows, 1978). Observations by Ochumbe (pers.comm.) have shown that, during the dry season, flamingos which feed on the algae migrate away from the lake. This may negatively affect the tourism industry.

Earlier studies on sediment, water and biota of the second largest natural lake in the world, Lake Victoria (Alale, 1981; Onyari, 1985; Ochieng, 1987) showed no significant heavy metal pollution. However, more recent studies in the same area revealed increased

lead levels largely due to increased shipping traffic and associated problems, car washing and discharges from local industries (Wandiga and Onyari, 1987; Onyari and Wandiga, 1989). Ochumba (1987) studied physico-chemical parameters, dissolved oxygen and heavy metal concentrations in Lake Victoria as the possible causes of periodic fish kills. The author attributed the fish kills to dissolved oxygen depletion.

In other East African areas, copper ion distribution in the surface waters of Lakes George and Edward (Idi Amin) in Uganda was studied alongside other chemo-limnological parameters (Buganyi, 1979). Concentrations ranged from 0.07 to 0.13 $\mu\text{g/ml}$ in Lake George and from 0.006 to 0.02 $\mu\text{g/ml}$ in Lake Edward. A direct relationship was established between copper, water hardness, alkalinity and total dissolved solids. Buganyi (1982) studied the occurrence of Cd, Cu and Fe in sediments of the same lakes and concluded that the concentrations, although distinct in the different water bodies, did not show much variations within each of the lakes.

Effluent, air and soil samples near a battery factory in Dar-es-Salaam, Tanzania, were analyzed for mercury by Semu *et al.* (1986). The highest levels of contamination were associated with the disposal of defective batteries. A preliminary investigation of the extent of metal pollution of the Msimbazi river in Dar-es-Salaam, which receives industrial, urban and agricultural waste waters, was conducted by analyzing sediments and biological indicators (Akhavuhaya and Lodenius, 1988). Metal concentrations were in general low but some of the results indicated localized industrial pollution.

Studies of dissolved metals in the marine environment were conducted by Norconsult (1977) concluding that the concentrations for Tudor Creek fell within the normal range of unpolluted natural sea water. Oteko (1987) studied the Mombasa Creek and suggested crustal sources to be responsible for copper concentrations and increased anthropogenic sources from automobile exhausts for cadmium and lead concentrations.

According to Bryceson *et al.* (1990) available data on marine contaminants are scarce. However, localized hot spots of metal pollution are found in the vicinity of cities and industrial centers that may constitute a danger to the public health. Wandiga and Onyari (1987) found slightly higher metal concentrations in marine fishes from Mombasa when compared to fish from Lake Victoria. The reported concentrations did not pose an immediate danger to the fish industry.

Matthews (1981) found evidence of surprisingly high mercury levels in fish (1.0-2.0 $\mu\text{g/g}$) and in hair and blood of inhabitants of Seychelles, where fish consumption is very high. The sources and pathways of such high mercury levels are a mystery.

6.4 Southern Africa

The concentrations and distributions of metals amongst other chemical contaminants were investigated by Graichus *et al.* (1977) in two South African lakes; Hartbeespoort dam, which receives industrial and municipal waters from Johannesburg and Voëlvllei dam, situated in mainly agricultural area. Water, sediment, aquatic plants and insects, fish, fish-eating birds and their eggs were analyzed for As, Cd, Cu, Mn, Pb, Zn and Hg. The results indicated higher levels in Hartbeespoort dam than in Voëlvllei for all metals

in sediments and birds, except for copper in bird carcasses. Mercury levels in birds were 2 to 5-fold greater than in fish, whereas lead values were 2 to 10-fold greater.

Greichus *et al.* (1978) investigated metals among other contaminants in Lake Mcllwaine, a eutrophic water body near Harare, Zimbabwe. Water, sediment, plankton, bottom fauna and fish were analyzed. The data gave intermediate levels of metals between those found in Hartbeespoort dam and Voëlvei dam.

Watling and Emmerson (1981) identified areas of metal input to the river Papenkuils which was considered to be a serious source of pollution to the marine environment around Port Elizabeth. In contrast, the estuary of river Swartkops was found generally unpolluted on the basis of metal concentration in water, surface sediments and sediment cores (Watling and Watling, 1982). Similar studies also showed that the estuary of river Knysna as well as the Bushmans, Kariëga, Kowie and Greatfish rivers were unpolluted (Watling and Watling, 1982a, 1983).

7. LEVELS OF HEAVY METALS IN DIFFERENT ENVIRONMENTAL COMPARTMENTS

In chapter 6 a qualitative presentation of selected African experiences by regions has been outlined; in chapter 7 a more detailed discussion will be presented on the quantitative aspects based on concentration levels in various environmental compartments.

In general, studies on the levels and distribution of contaminants including heavy metals in Africa have been concentrated in urban and industrial areas. Thus the actual background levels in water, sediments and biota may still not be accurately known and this fact can also produce bias in the interpretation of the data.

7.1 Concentrations of metals in water

Data of dissolved metals in inland water bodies (lakes and rivers) and coastal marine zones are presented in Table III. More data are available for inland than for coastal waters. As already pointed out, most studies on the levels and distribution of heavy metals in Africa have concentrated on urban and industrialized areas.

Mercury showed the lowest concentrations ($< 1.0 \mu\text{g/l}$), followed by cadmium ($0.2\text{--}21.0 \mu\text{g/l}$). Iron gave the highest levels in most waters with a considerable wide range of variation, from $2.5 \mu\text{g/l}$ in the river Nile, Egypt (El-Rayis and Saad, 1985), to $14,400 \mu\text{g/l}$ in Shasha stream, Nigeria (Martins, 1978). The other metals are generally arranged in the following order of abundance: $\text{Mn} > \text{Zn} > \text{Pb} > \text{Cu} > \text{As}$. The levels of metals in the coastal waters were markedly lower than those found in most inland waters. This reflects the direct influence of pollution on the lakes and rivers. Undoubtedly, the very high concentrations of certain metals found in specific waters are a result of acute pollution.

Table III
Mean dissolved metal concentrations in inland and coastal waters (ng/ml)

Location	Hg	Cd	Pb	As	Cu	Zn	Mn	Fe	Reference
INLAND WATERS									
River Nile, Egypt		0.4			1.3	8.18	0.46	2.5	El Rayes and Saad, 1985
Lake Mariout, Egypt		0.22			10.5	16.3		42.5	Saad, 1985
Norcha Hydrotrome, Egypt		0.2			20.5	17.1		40.1	Saad, 1987
Kpong Headpond, Ghana	<1.0	<10	<20		<20	<20	45	90	Biney, 1991
Groundwater, Ghana	<1.0	<10	92		17.5	80	<20	924	Pelg-Ba et al., 1991
Kaduna River, Nigeria					240	200	1,300	3800	Martins, 1978
Oyi River, Nigeria					100		300	1800	Ajayi and Osibanjo, 1981
Ora River, Ibadan, Nigeria		0.40	5.0		8.0	7.5	450	1247	Monteshora et al., 1981
ITA Lake, Ibadan, Nigeria		0.95	1.3		0.8	1.5	212	436	Monteshora et al., 1981
Agodi Lake, Ibadan, Nigeria		0.84	4.9		2.3	4.7	774	1375	Monteshora et al., 1981
Oyunga Sfr., Ibadan, Nigeria		0.38	13.1		8.9	5.8	1,155	2213	Monteshora et al., 1981
Shasha Sfr., Lagos, Nigeria			100		900	70	2,900	14400	Martins (1978)
Calabar River, Nigeria		1.35	13.9		3.2	10.3		188	Kakulu and Osibanjo, 1992
Warri River, Nigeria		2.3	17.9		23.1	42.9		625	Kakulu and Osibanjo, 1992
Lake Nakuru, Kenya	<1.0	21	5	6	2	49	24		Grechus et al., 1978a
Lake Victoria, Kenya		2.8	793.6		5-57.6	25-125	50-3,276		Ochieng, 1987
Lake George, Uganda			6		100			4830	Bugenyi, 1982
Lake Edward, Uganda			1.1		15			89	Bugenyi, 1982
Lake Malawi, Zimbabwe	<1.0	1	10	3	10	12	32		Grechus et al., 1978
Hartbeespoort Dam, S. Afr.	<1.0	1	4	1	3	36	45		Grechus et al., 1977
Vaalwater Dam, S. Africa	<1.0	2	12	3	13	25	38		Grechus et al., 1977
Kynasa River, S. Africa	0.01-0.19	<0.110	<0.18		<0.1-2.4	<0.1-26	1.1-40	40-510	Watling and Watling, 1982a
COASTAL WATERS									
Southwest, Mediterranean	0.024								Bernhard, 1988
Red Sea, Egypt	<0.002				5.1		0.83	16.2	Saad and Kandiel, 1988
Accra, Ghana									Portmann et al., 1989
Lagos Lagoon, Nigeria		2	9.0		3.0	15	21	86	Okoye, 1991a
BACKGROUND									
Rivers		0.02	3	1.7	7	20	7	40	Burton, 1976,
Coastal Waters		0.01	0.03	1.5	1	2.5	0.4	2	Martin and Whitfield, 1983

* Range values

Table IV
Mean metal concentrations in inland water sediments ($\mu\text{g/g}$ dry weight)

Location	Hg	Cd	Pb	Cu	Zn	Mn	Felix ¹⁰	References
Lake Marout, Egypt		0.20	7.3	38.0	94	958	25.6	Saad <i>et al.</i> , 1985
Lake Nouria, Egypt		0.15	10.6	79.6	106	1,250	57.8	Saad <i>et al.</i> , 1985
Lake Manzalah, Egypt		0.17	9.6	207	119	766	44.5	Saad <i>et al.</i> , 1985
River Nile Estuary, Egypt		1.06		85.6	139	387	0.46	Saad and Fahmy, 1985
Kpong Headpond, Ghana		<0.20	29.3	30.3	49	352	60.5	Biney, 1991
Lower Volta River, Ghana		<0.20	16.7	28.9	34	295	54.5	Biney, 1991
River Wuni, Ghana	0.21	0.16	13.4	4.7	16			Biney and Pecko, 1991
Niger Delta, Nigeria	0.33	0.79	32.1	23.9	62	349	20.7	Kakulu and Osiabayo, 1988
Lake Victoria, Kenya*		0.55-1.02	6.02-69.4	0.96-78.6	2.54-265	53.1-616	1.18-52.9	Onyiah and Wandiga, 1989
Lake Nakuru, Kenya	<0.05	0.27	34.0	6.2	140	550		Grechus <i>et al.</i> , 1978a
Lake George, Uganda		3.80		102			69.0	Bugenyi, 1982
Lake Edward, Uganda		2.70		37.0			5.5	Bugenyi, 1982
Lake Mchizame, Zimbabwe	0.28	0.39	41.0		100	350		Grechus <i>et al.</i> , 1978
Haarbesport Dam, S. Afr.	0.60	0.87	63.0	41.0	260	680		Grechus <i>et al.</i> , 1977
Voelvlin Dam, S. Africa	0.06	0.19	9.0	15.0	49	340		Grechus <i>et al.</i> , 1977
Papenkulis River, S. Africa	0.35	102.3	170.7	71.4	289	150	12.0	Watling and Emmerson, 1981
Swartkops River, S. Africa	0.02	1.0	17.8	10.5	35.5	177	15.5	Watling and Emmerson, 1981
Continental Crust	0.08	0.10	12.5-20	55	70	950	56.0	Taylor, 1964
Unpolluted Sediments	0.05-0.3	0.11	19	33	95	770	41.0	GESAMP, 1982; Salomons and Förstner, 1984

*Range values

7.2 Concentrations of metals in sediments

On a continental basis, heavy metal inputs into African inland water sediments (Table IV) pose no great concern in relation to unpolluted sediments (GESAMP, 1982).

Most water bodies showed low-to-moderate metal concentrations except for Hartbeespoort dam and river Papenkuils in South Africa, the Niger delta in Nigeria and lakes George and Edward (Idi Amin) in Uganda. Lakes Nozha, Mariut and Manzalah and the river Nile in Egypt as well as Lake Mchilweine in Zimbabwe also showed elevated concentrations of some metals which clearly indicate considerable anthropogenic inputs.

Metal concentrations in inland water sediments thus pose no environmental concern for the continent except for the above-mentioned areas which may be considered as hot spots within their respective regions.

Heavy metal concentrations in the African marine and coastal sediments (Table V) fell within the ranges given for Hg, Cd, Pb and As by GESAMP (1985, 1988) but higher values occurred in some areas. For example, sediments from Lagos lagoon in Nigeria had high concentrations of lead and iron while the Ebrié Lagoon in Côte d'Ivoire had high mercury, zinc and iron concentrations. The results revealed largely anthropogenic heavy metal enrichment implicating urban and industrial runoff into coastal lagoons which have poor water exchange (Okoye, 1989; Kouadio and Trefry, 1987). However, data for Egypt (Saad *et al.*, 1981, 1981b) and the Nigerian Atlantic coast (Ndiokwere, 1984) did not suggest high contamination of the coastal sediments.

7.3 Concentration of metals in aquatic fauna

Heavy metal concentrations in freshwater fish muscle are presented in Table VI. Some differences between water bodies were observed with respect to the levels of certain elements in finfish. For example, zinc showed relatively higher values in samples from Lake Nakuru, Kenya, followed in decreasing order by those from Zimbabwe and South Africa, Egypt, Nigeria and Ghana. Likewise, copper concentrations were higher in samples from Egypt and lakes Nakuru and Mchilweine. Although data for iron were scarce, the concentration of this element also seemed higher in samples from Egypt.

However, on the whole, the levels of metals in inland water fish muscle were below WHO limits, except for lead in *Macrobrachium* sp. from the Niger Delta, Nigeria and lower Volta River, Ghana.

Data on heavy metal concentrations in marine finfish and shellfish are summarized in Table VII. As for inland waters, the levels in marine organisms were generally below WHO limits except for some hot-spots. Cadmium and mercury for example showed the same low trends in both fin- and shellfish. In contrast, marine organisms from Nigeria had lead levels which exceeded the WHO limit. This may be attributed to a higher state of contamination from the use of leaded gasoline.

Table V
Mean metal concentrations in marine sediments ($\mu\text{g/g}$ dry weight)

Location	Hg	Cd	Pb	Cu	Zn	As	Fe($\times 10^3$)	Reference
MEDITERRANEAN								
Abu Kır Bay, Egypt		2.02		12	102		4.5	Saad et al., 1981b
Port Said, Egypt		3.2		14	50		2.5	Saad et al., 1981b
Eastern Harbour, Alexandria, Egypt		2.89		14	51		1.1	Saad et al., 1981b
El Mex, Egypt		2.18		24.1	35.4		1.47	Saad et al., 1981
South western Mediterranean	0.12							Bernhard, 1988
GULF OF GUINEA								
Ebrié Lagoon, Côte d'Ivoire	0.35		57.6	37.0	187		52.40	Kouadio and Trefny, 1987
Lagos Lagoon, Nigeria		4.10	178.9	15.0	147		36.38	Okoye et al., 1991
Atlantic coast, Nigeria*	0.10	2.30	67.5		72.5	6.2		Ndriokwere, 1984
INDIAN OCEAN								
Krynska Lagoon, South Africa	0.019	0.23	48.4	6.7	40.6			Watling and Watling, 1982a
UNPOLLUTED SEDIMENTS	0.01-0.08	0.2-5.0	8-60			14		GESAMP, 1985, 1988

*Median values

Table VI
Mean metal concentrations in inland water fish ($\mu\text{g/g}$ fresh weight)

Location	Hg	Cd	Pb	As	Cu	Zn	Mn	Fe	References
FINFISH									
Lake Mariut, Egypt	0.01	0.15	0.67	0.031	3.7	7.6	0.9	11.2	Saad <i>et al.</i> , 1981a
Lakes Ioku, Mariut, Egypt		0.004			1.77	7.4			El Nabawi <i>et al.</i> , 1987
Nozha		0.05			3.14	8.0		12.6	Saad, 1987
Hydriodrome, Egypt	0.053	<0.10	0.43		0.36	5.6		3.8	Biney, 1991
Kpong Headpond, Ghana	0.37	0.19	0.47		0.18	3.0	0.63		Biney and Beako, 1991
River Wiwa, Ghana	0.034	0.03	0.48		0.70	4.8	1.1		Kakulu <i>et al.</i> , 1987a
Niger Delta, Nigeria	0.044	0.05	0.17	0.36	2.0	22	1.8	5.4	Grechus <i>et al.</i> , 1978a
Lake Nakuru, Kenya		0.04-0.12	0.4-1.1		0.15-0.53	2.21-7.02	0.22-0.74	0.53-4.65	Wandiga and Onyari, 1987
Lake Victoria, Kenya		0.02	0.17	0.28	1.08	9.6	5.4		Grechus <i>et al.</i> , 1978
Lake Malawi, Zimb.		0.02	0.05	0.26	0.66	11.8	1.6		Grechus <i>et al.</i> , 1977
Hartbeespoort Dam, S.A.		0.01	<0.02	0.40	0.30	6.6	0.24		Grechus <i>et al.</i> , 1977
Volhvie Dam, S. Africa									
SHELLFISH									
<i>Macrobrachium</i> sp.	0.04	<0.10	4.36		11.0	16.1			Biney, 1991
Lower Volta R., Ghana	0.02	0.04	2.47		8.5	14.1			Kakulu <i>et al.</i> , 1987a
Niger Delta, Nigeria									Biney, 1991
<i>Egeria radiata</i>	0.05	<0.10	1.37		4.5	20.2			
Lower Volta R., Ghana									
WHO Limits	0.05**	2.0	2.0		30	1000			Kakulu <i>et al.</i> , 1987a

* Range values ** Action level adopted in many countries

Table VII
Mean metal concentrations in marine fish ($\mu\text{g/g}$ fresh weight)

Location	Hg	Cd	Pb	Cu	Zn	Reference
FINFISH						
Egypt	0.077	0.004	0.07	1.65	4.23	El Nabawi <i>et al.</i> , 1987
Senegal	0.17	<0.10	0.50	0.73	4.55	83, 1988
Côte d'Ivoire	0.11	<0.25		<0.80	4.86	Métongo, 1988
Ghana	0.064	<0.10	0.36	0.46	4.63	Institute of Aquatic Biology, 1990
Ghana	0.24					Ntow and Khwaja, 1989
Nigeria		<0.10	2.28	11.3	27.5	Okoye, 1991
Cameroon	0.09	0.26				Mbome <i>et al.</i> , 1985
Cameroon	0.06	<0.10	1.83	0.75	5.55	Mbome, 1988
Kenya*		0.04-0.38	1.22-5.48	0.36-2.04	4.67-40.8	Wandiga and Onyiah, 1987
SHELLFISH						
Penaeus sp.						
Senegal	0.17	<0.10	<0.50	4.68	13.9	83, 1988
Côte d'Ivoire	0.042	<0.25		6.02	17.9	Métongo, 1988
Ghana	0.033	<0.10	0.82	6.16	14.9	Institute of Aquatic Biology, 1990
Nigeria		0.18	5.10	23.6	240	Okoye, 1991
Cameroon	0.057	<0.10				Mbome <i>et al.</i> , 1985
Cameroon	0.070	0.21		9.5	40.4	Mbome, 1988
<i>Crassostrea</i> sp.						
Côte d'Ivoire	0.125	0.65		24.5	1205	Métongo, 1981
Nigeria		0.17	2.09	5.80	628	Okoye, 1991
Cameroon	0.072	0.56				Mbome <i>et al.</i> , 1985
Cameroon	0.063	0.25		8.45	407	Mbome, 1988
South Africa		1.62	0.08	2.35	213	Watling and Watling, 1982a
WHO Limits	0.5**	2.0	2.0	30.0	1000	Kakulu <i>et al.</i> , 1987a

*Range: values ** Action level adopted in many countries

Review of heavy metals

In support of what has been reported in several studies (Hellewell, 1986; Kakulu and Osibenjo, 1986; Kakulu *et al.*, 1987; Institute of Aquatic Biology, 1990), shellfish had higher concentrations of most metals. The highest concentrations of cadmium, copper and zinc occurred in *Crassostrea* sp. which has a great capacity to accumulate contaminants and is a biological indicator of pollution.

7.4 Concentration of Metals in Aquatic Flora

Aquatic plants have been shown to accumulate heavy metals in their tissues and therefore have been used as biological indicators for metal pollution monitoring in the aquatic ecosystem. Table VIII shows the distribution of heavy metals in aquatic plants. Generally, the levels in aquatic plants from inland waters were higher than in those from coastal waters. The variability in the levels of heavy metals in different regions could be ascribed to biological variation between the species rather than environmental factors. Nonetheless, higher concentrations of cadmium were found in *Ceratophyllum* from industrial areas in Egypt compared to relatively unpolluted areas (Fayed and Abd El-Shafy, 1985). Furthermore, it is significant that an excessively high value of lead (78.0 µg/g) was found in blue-green algae from Lake Mchlwane, Zimbabwe (Greichus *et al.*, 1978) compared to the rest of the region.

7.5 Comparison between metal contents in sediments and biota

Comparisons between heavy metal concentrations in sediments and biota of selected African waters are shown in Table IX. In Egypt all metals except cadmium showed higher values in the sediments than in fish (Saad, 1985a, 1987). In Ghana only iron and lead followed this pattern, whereas the other metals gave higher values in certain flora and fauna (Biney, 1991a). In Kenya the metals accumulated in higher concentrations in sediments than in fish (Wandiga and Onyari, 1987). In Southern Africa the same pattern occurred with few exception (Greichus *et al.*, 1977). The levels of accumulation of metals in the different flora and fauna did not follow the same pattern.

7.6 Comparison between different sub-regions in Africa

In Tables X and XI are presented the trace metal concentrations in sediments and in fish muscle and shellfish from the major African sub-regions, Northern, Western, Eastern and Southern Africa. The data presented are ranges of means based on Tables IV and V for sediments and Tables VI and VII for fin- and shellfish. Hot-spots, i.e., abnormally high concentrations were excluded from the calculations since the objective is to compare actual background levels from the different sub-regions in Africa.

An inspection of Tables X and XI shows inadequacy of data especially for the coastal and marine areas. In spite of this, the four regions exhibit comparable concentrations of trace metals in both inland and coastal fish and sediment. Mercury for example, occurred in finfish within the narrow ranges of 0.01 to 0.053 µg/g fresh weight for inland fishes and 0.06 to 0.17 for marine fishes. Corresponding values for cadmium were 0.004 to 0.19 and 0.004 to 0.36 µg/g fresh weight.

Table VIII
Mean metal concentrations in aquatic plants ($\mu\text{g/g}$ dry weight)

Location	Hg	Cd	Pb	As	Cu	Zn	Mn	Fe	References
INLAND WATERS									
River Nile, Egypt									
<i>Ceratophyllum</i> (clean site)		<0.05	2.7		2.7	13.8			Fayed and Abd El Shafy, 1985
<i>Ceratophyllum</i> (industrial site)		0.30	22.2		36.4	117.0			Fayed and Abd El Shafy, 1985
Lower Volta River, Ghana									
<i>Ceratophyllum</i>	0.37	0.99	17.4		12.2	45.4	3332	2579	Biney, 1991
<i>Asiia stratiotes</i>	0.31	0.93	22.6		12.6	39.8	2259	3852	Biney, 1991
<i>Potamogeton octandrus</i>	0.25	<0.20	9.4		5.3	12.5	2370	1113	Biney, 1991
<i>Valisneria spiralis</i>	0.13	1.33	23.2		12.6	42.9	1809	3560	Biney, 1991
Lake Malawi, Zimbabwe									
Blue-green algae	0.26	1.5	78	2.9		190	220		Greichus et al., 1978
Harboursport Dam, S Africa									
Algae	1.6	0.06	<0.10	1.5	2.7	39.0	96		Greichus et al., 1977
<i>Eichhornia</i>	0.71	0.23	2.6	4.1	12.0	42.0	840		Greichus et al., 1977
COASTAL WATERS									
Accra, Ghana									
<i>Ulva fasciata</i> (Green algae)	<0.10	<0.2	8.3		6.9	24.8		163	Environ. Management Associates, 1989
<i>Sargassum vulgare</i> (Brown algae)	<0.10	<0.2	8.5		7.2	37.8		342	Environ. Management Associates, 1989
<i>Polysiphonia divaricata</i> (Red Algae)	<0.10	1.4	8.6		4.5	33.0		452	Environ. Management Associates, 1989

Table IX
Comparison of trace metal concentrations in sediments, fauna and flora ($\mu\text{g/g}$ dry weight)

Matrix	Hg	Cd	Pb	Cu	Zn	Mn	Fe	As	References
INLAND WATERS									
Lake Mariut, Egypt Sediment Finfish		0.07 0.25		91 23	162 59		4747 257		Saad, 1985a Saad, 1985a
Nozha Hydrodrome, Egypt Sediment Finfish		0.16 0.47		133 34	156 41		8628 109		Saad, 1987 Saad, 1987
Lower Volta River, Ghana Sediment Macrophytes Shellfish Finfish	0.29 0.19 0.29	<0.2 0.89 <0.2 <0.2	21.7 18.8 6.0 2.3	29.5 11.2 38.2 2.0	39.1 37.8 69.1 30.7	318 2560 33.2 3.4	56821 2922 80.1 19.0		Biney, 1991 Biney, 1991 Biney, 1991 Biney, 1991
Hartbeespoort Dam, S.Afr. Sediment Algae Macrophytes Finfish	0.60 1.60 0.71 0.52	0.87 0.06 0.23 0.05	63 <0.1 2.6 1.0	41 2.7 12 2.9	260 39 42 120	680 96 840 12		75 1.5 4.1 2.3	Greichus et al., 1977 Greichus et al., 1977 Greichus et al., 1977 Greichus et al., 1977
Lake Victoria, Kenya* Sediment Finfish		0.55-1.02 0.04-0.12	6.02-69.4 0.39-1.08	0.19-78.6 0.15-0.53	2.54-265.2 2.2-7.02	53.7-618 0.12-0.74	1180-52880 0.53-4.65		Wandiga and Ohyan, 87 Wandiga and Ohyan, 87
COASTAL WATERS									
Mediterranean, Egypt Sediment Finfish		2.18 0.02		24.1 8.25	35.4 21.2	151	1470		Saad et al., 1981 El Nabawi et al., 1987

* Range values

Table X
Metal concentrations in sediment from the major African sub-regions ($\mu\text{g/g}$ dry weight)

Sub region	Hg	Cd	Pb	Cu	Zn	Mn	Fe($\times 10^3$)
INLAND WATERS							
Northern Africa		0.15-0.20	7.3-10.6	38.0-95.6	94-139	387-958	0.46-58
Western and Central Africa	0.21-0.33	0.16-0.20	13.4-16.7	24.7-30.3	16-62	295-352	55-60
Eastern Africa	<0.05	0.27-1.02	6.02-18.1	0.96-6.2	2.54-140	53-550	1.18-69
Southern Africa	0.02-0.28	0.19-1.0	9.0-17.8	10.5-41.0	36-289	150-350	12-16
COASTAL WATERS							
Northern Africa	0.12	2.02-3.20		12-14	35-51		1.1-4.5
Western and Central Africa	0.10-0.35	2.30-4.10	57.6-67.5	13.37	73-187		36-52
Southern Africa	0.019	0.23	48.4	6.7	41		

Table XI
Metal concentrations in fish from the major African sub-regions ($\mu\text{g/g}$ fresh weight)

Sub-region	Hg	Cd	Pb	As	Cu	Zn	Mn	Fe
FINFISH								
Inland Waters								
Northern Africa	0.010	0.004-0.15	0.67	0.031	1.77-3.70	7.4-8.0	0.9	11.2-12.6
Western and Central Africa	0.034-0.053	0.03-0.19	0.43-0.48		0.18-0.70	3.0-5.6	0.63-1.1	3.8-5.4
Eastern Africa	0.044	0.04-0.12	0.17-1.1	0.036	0.15-2.0	2.2-22	0.74-1.9	0.53-4.7
Southern Africa		0.01-0.02	0.02-0.17	0.26-0.40	0.30-1.08	6.6-11.8	0.24-5.4	
Coastal Waters								
Northern Africa	0.077	0.004	0.07		1.65	4.23		
Western and Central Africa	0.06-0.17	0.10-0.26	0.36-2.28		0.46-11.3	4.55-27.5		
Eastern Africa		0.04-0.36	1.22-6.48		0.36-2.04	4.67-40.8		
SHELLFISH								
Western and Central Africa								
<i>Penaeus</i> sp.	0.033-0.17	0.10-0.25	0.50-5.10		4.68-23.6	13.9-240		
<i>Crassostrea</i> gasar	0.072-0.13	0.17-0.65	2.09		5.8-24.5	407-1205		
Southern Africa								
<i>Crassostrea magallanica</i>			0.05		4.0	229		

Table XII
Comparison of metal concentrations in sediment from Africa and other areas of the world ($\mu\text{g/g}$ dry weight)

Location	Hg	Cd	Pb	Cu	Zn	Reference
African inland waters	0.24 (0.02-0.60)	0.37 (0.10-1.0)	23.2 (7.3-63)	26.3 (0.96-41)	82.5 (2.54-140)	This study
African coastal waters	0.19 (0.1-0.35)	2.78 (2.0-4.1)	57.8 (48-68)	19.4 (12-37)	92 (35-102)	This study
North-east Ontario lakes				10.5-2900	130-448	Bradley and Morris, 1986
Narragansett Bay, USA		0.06-2.45	17.81	36-98	53-168	Esler et al., 1977
River Tawe, Wales		39	862	326	5107	Vivian and Muscoe, 1977
Liverpool Dock, UK			109-613	90-1592	734-2087	Beilinger and Benham, 1987
Portsmouth Harbour, UK		0.5-3.3	49-114	26-72	61-210	Soulsby et al., 1978
Evros Gulf, Greece					52-147	Angelidis et al., 1981
Straits of Malacca	0.4-1.1	ND*-125	6.5-35.3	1.0-26.3		Sen Gupta et al., 1990
Behram	13-106	0.02-0.05	1.70-15.1	5.60-10.0		Sen Gupta et al., 1990
Kuwait	50-170	0.09-0.23	3.3-68	20.1-21.9		Sen Gupta et al., 1990
Saudi Arabia	3-37	2.5-5.0	0.6-4.2	5.4-16.6		Sen Gupta et al., 1990
Hong Kong				22	4.0-23	Linden et al., 1990
South China Sea		0.41-2.39		1.94-9.21	96	Gomez et al., 1990
Jakarta Bay	0.05-4000	5.0-400		10-780	12.5-49.9	Gomez et al., 1990
Wellington Harbour, New Zealand			22-6740	15-216	55-2270	Brodie et al., 1990
Fiji	<0.2	1.1-2.2	6.8-10	85-150	54-220	Brodie et al., 1990

* ND - Not Detected

Table XIII
Comparison of metal concentrations in fish from Africa and other areas of the world ($\mu\text{g/g}$ fresh weight)

Location	Hg	Cd	Pb	Cu	Zn	Reference
African inland waters	0.035 (0.01-0.053)	0.053 (0.004-0.19)	0.31 (ND*-0.67)	0.85 (0.18-2.0)	7.16 (3.0-11.8)	This study
African coastal waters	0.095 (0.06-0.17)	0.059 (ND-0.26)	0.69 (0.07-1.83)	0.80 (0.40-1.65)	4.75 (4.23-5.55)	This study
British rivers	0.17 (0.023-0.32)	0.15 (ND-0.35)	0.87 (ND-4.30)			Mason, 1987
Northern Tyrrhenian Sea	1.21 (0.11-2.81)	<0.02	<0.20	0.37 (0.24-0.44)	3.92 (2.92-5.19)	Leonzi et al., 1981
Finnish lakes	0.77 (0.50-4.06)					Surma-Aho et al., 1986
Northern Indian Ocean						Sen Gupta et al., 1990
Bahrain	0.01	0.90	0.62	0.81		Linden et al., 1990
Straits of Malacca	0.004-1.07	0.00003-0.071		0.10-0.47		Gomez et al., 1990
Indonesia	0.01-0.58	ND-0.10	ND-1.20	0.05-0.75	1.70-10.8	Gomez et al., 1990
Gulf of Thailand	0.02-0.20	0.02-0.03	0.09-0.68	0.33-0.68	0.30-9.96	Gomez et al., 1990
Philippines	0.01-0.10	0.01-0.06	0.01-0.09	0.50-1.25	6.20-11.8	Gomez et al., 1990
Hong Kong	0.01-1.10	ND-0.36	0.01-0.08	ND-4.43	0.20-58.4	Gomez et al., 1990
New Zealand	ND-0.40	ND	ND-0.30	ND-1.10	0.80-25.4	Gomez et al., 1990
Papua New Guinea	0.02-1.10	0.01-0.03	0.03-0.18	0.12-0.75	0.80-5.1	Brode et al., 1990
	0.03-0.40	ND-0.10	ND-0.30	0.30-0.70	3.0-5.0	Brode et al., 1990

* ND - Not Detected

Where comparable data were available, coastal fishes showed slightly higher maximum values of trace metals than inland fishes. This was also true for sediments and may be due to the data originating mainly from coastal lagoons which are normally heavily influenced by anthropogenic activities.

7.7 Comparison of African data with some other areas of the world

The levels of heavy metals in sediments and finfish from African inland and coastal waters are presented alongside data from some other areas of the world in Tables XII and XIII. The means and ranges for African waters were calculated from Tables IV and V for sediments and Tables VII and VIII for fish, excluding the hot spots.

Comparison of such data may be difficult since data calculated for the whole African region are being judged in relation to selected individual areas and sites of the world which may not be representative for their regions. Moreover, different species of fish and fractions of sediments were analyzed. Also, information on sex and weight is often lacking, and comparison is further complicated by the differences in data presentation. For example, analytical results may be presented as means or ranges on a dry or wet weight basis.

The above notwithstanding, the occurrence of trace metals in African aquatic systems is not excessive when compared to some other areas of the world. For example, mean mercury levels in fish were lower by an order of magnitude compared to values reported for mullets in the Tyrrhenian Sea, an area close to naturally occurring mercury deposits (Leonzi *et al.*, 1981). They were, however, similar to levels in other tropical, less industrialized areas like Indonesia and Thailand (Gomez *et al.*, 1990). The maximum cadmium concentrations were also low compared to fish from British rivers (Mason, 1987) and from the coast of the Philippines (Gomez *et al.*, 1990), but they were within the same range as levels in other areas.

With the exception of lead, inland and coastal water sediments also had comparable or relatively low contents of Hg, Cd, Cu and Zn. Admittedly, these comparisons are based on data which exclude hot spots. However, the low occurrence of heavy metals in African aquatic environments indicate low inputs of contaminants containing trace metals, compared to the more industrialized regions.

8. CONTROL MEASURES

In view of the expected increase in industrialization and urbanization in most African countries, it is still important to formulate pollution control policies that take into account the need to regulate discharges of contaminants into aquatic systems.

In spite of the actual relatively low inputs of contaminants, there is increasing awareness of the need to control waste discharges into the environment. In general, many African countries, aware of the possible detrimental effects, have formulated various laws to control aquatic pollution, although many of these are not enforced.

Since trace metals originate from both domestic and industrial discharges, the control of these sources would also serve to control trace metal contamination of the environment. In addition to legislation, control measures should include the formulation of standards and criteria, effluent treatment, monitoring, environmental training and education programmes. These aspects have been treated in detail for African inland in this publication on pages 7 ff and 23 ff, respectively, and can equally well apply to coastal waters.

It is also important to add that, as part of the objectives of pollution control, emphasis should be placed on the need to minimize waste generation. Industries should be encouraged to adopt low- and non-waste technologies (LNWT) at all stages of a product's life, i.e. raw material extraction, production, use and disposal. For planned and proposed industries the achievement of LNWT is possible through the assessment of their potential impacts on the environment and through the adoption of clean manufacturing processes in the design stage. Environmental auditing which involves self-regulation should also be encouraged within the business community as part of an overall environmental management policy. The advantage here is that self-regulation is frequently more effective than reliance on official rules which may not cover every contingency.

9. CONCLUSIONS

This review of heavy metals in the African aquatic environment has shown that available data originate from only a few areas of the continent, are scattered and may be inconsistent in some cases. Besides, depending on the area, more information may exist on coastal than on inland areas or *vice versa*. It is also not possible to establish a trend in heavy metal accumulation since data cover only a narrow period of time. There is, therefore, a need to generate more data covering the different environmental compartments in all the African sub-regions.

Despite this inadequacy, some conclusions may be drawn from this review. Generally, lower concentrations of heavy metals occur in African aquatic systems compared to other areas of the world. Concentrations in inland and coastal environments exhibit no significant differences and on a continental level, the four geographical areas - Northern, Western, Eastern and Southern Africa - have similar low levels. There are however some hot-spots, such as Lake Meriut, Lagos lagoon, Ebrié lagoon and Hartbeespoort dam.

With the expected increases in urbanization and socio-economic activities, there is the need to identify the sources and quantify the discharges of heavy metals into aquatic environments on a national basis. It is also important to formulate pollution control measures in each country which should cover legislation, standards and criteria, waste minimization, effluent treatment, monitoring, training, education and public awareness.

CHLORINATED HYDROCARBON SUBSTANCES

by

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1. INTRODUCTION

Chlorinated hydrocarbon substances (CLHCs) are synthetic organochlorine compounds and include pesticides (e.g. DDT and derivatives, hexachlorocyclohexane (HCH), eldrin, dieldrin, heptachlor and endosulfan) as well as some commercial or industrial chemicals such as polychlorinated biphenyls (PCBs), dioxins (PCDDs) and hexachlorobenzene (HCB). These chemicals are lipophilic with low volatility and low water solubility and have been in use in both developed and developing countries for several decades. The organochlorine pesticides (OCPs), for example, are deliberately introduced into the environment and have played a major role in increasing worldwide food production and protecting human health and natural resources, eg DDT and aldrin (Ware, 1989). The industrial chemicals such as PCBs, however, are introduced indirectly into the environment (Alford-Stevens, 1986).

It has been recognised that the persistence and bioaccumulative tendency of these substances, their metabolites and residues in the environment make them not to remain where they are applied but instead partition between the major environmental compartments in accordance with their physico-chemical properties and may thereby become transported several kilometres from the point of their original release (Heque and Freed, 1975). Such environmental distribution may lead to exposure of living organisms including man, that are far removed from intended targets.

These substances are micro-organic pollutants and are included in the priority list of pollutants (Keith and Telliard, 1979) because of their toxicity, ecological effects and toxicological hazards (Khan, 1977) including human disaster episodes associated globally with their use and accidental release into the environment. The manufacture and use of some CLHCs (e.g. DDT and PCBs) have therefore been banned or restricted in the developed countries. Nonetheless, the use of these chemicals still thrives in most developing countries due to lack of appropriate national regulatory control and their relatively low prices, compared to the more expensive alternative, less persistent, chemicals.

Population explosion, rapid urbanisation and industrialisation have increased reliance on the use of CLHCs in Africa in agriculture, public and animal health (e.g. DDT) and in electric transformers and capacitors (e.g. PCBs) for power generation. Data exist on the production and use of these chemicals in the developed countries (WHO/UNEP, 1990; Miller, 1982), but such data are not readily available in Africa. Nonetheless, pesticide usage in Africa is much less compared to India, Europe and North America. For example 60,000 tonnes of DDT were produced globally in 1974 with the United States of America (USA) consuming about 66% of these (40,000 tonnes) (WHO, 1979).

Chlorinated hydrocarbon substances

Estimated total global production and use of PCBs is 2 million tonnes (Hansen, 1987). Balk and Koeman (1984) had reported the following total pesticide consumption for 1977: Indonesia 5,400, Thailand 20,600, Gambia 50, Côte d'Ivoire 1,030 and Sierra Leone 30 tonnes. They also predicted similar growth rates which means that the same trends hold for the 1990s. Although most of the pesticides used in Africa are imported, there are a few production facilities in some countries for OCPs, e.g. Nigeria, Senegal, South Africa, Côte d'Ivoire and Egypt. It is estimated that about 25,000 tonnes of OCPs are in use in the region (see chapter 2).

Chlorinated hydrocarbons have low solubility in water (e.g. DDT: 1.2 µg/l). Being lipophilic, these substances can be concentrated to harmful levels in the aquatic environment through bioaccumulation, biomagnification and biogeochemical processes (Edwards, 1977). Consequently, aquatic organisms that are commercially exploited for human food may pose a risk to man. Hence the levels of CLHCs in the aquatic environment including organisms have been continuously measured in surveillance and monitoring programmes in most developed countries (Suzuki *et al.*, 1977; Picer and Picer, 1979; Wegman and Greve, 1980; Gayner *et al.*, 1984; UNEP/WHO, 1988).

Protection of the aquatic environment and associated resources is included in chapters 17 and 18 of Agenda 21, the United Nations Programme of Action from the Rio Earth Summit, for achieving sustainable development for the rest of this and into the next century (United Nations, 1993). It has been estimated that 80% of illness in developing countries is attributed to unsafe water supplies (Harries *et al.*, 1990). Therefore, national, regional and international strategies for implementing Agenda 21 have to be put in place. However, the lack of scientific and ecotoxicological data on chemical pollutants, effective for the control and prevention of aquatic pollution has been recognised in Africa (see pages 7 ff of this publication). In particular, the paucity of data on CLCH levels in environmental media in the region was highlighted at the Workshop on marine pollution monitoring in West and Central African Region, held in Senegal, 1985 (IOC-Unesco, 1985).

Meaningful development of management policies and regulatory framework for the protection of the aquatic environment in the region can only be achieved on the availability of reliable and adequate scientific data generated in the region. To this end, various coastal and marine pollution monitoring programmes and research studies were initiated in the early 1980s in various universities and research institutes in Africa under the aegis of UNEPs Regional Seas Programme. The pertinent programmes are the Mediterranean Pollution Research Programme (MEDPOL) in North Africa, the West and Central Africa Marine Pollution Research Programme (WACAF 2) and the Eastern Africa Marine Pollution Research Programme (EAF/6) respectively.

As Africa embarks on the transition to sustainable development for the present and future generations, this review on levels of chlorinated hydrocarbons in the aquatic environment (streams, rivers, lakes, estuaries and coastal waters) including sediments and biological organisms complements an earlier review of trace metal levels in the African aquatic environment (see pages 32 ff of this publication) aimed at fostering a holistic approach towards the formulation of management and regulatory policies on the protection of the aquatic environment and its resources in the region.

2. SOURCES AND PATHWAYS OF CHLORINATED HYDROCARBONS

Anthropogenic activities provide the primary point source of chlorinated hydrocarbons input into the aquatic environment. The organochlorine pesticides (OCPs) enter the aquatic environment mainly by deliberate application or accidentally, while PCBs entry into the aquatic environment is indirect and principally accidental.

Agricultural production of food for the continent's rapidly growing population (3-4% annually) and cash crops for economic buoyancy as well as disease vector control activities since the 1940s, represent major anthropogenic sources of OCP inputs into the aquatic environment. These substances are sometimes applied directly to water bodies to control aquatic pests, snails, weeds and mosquito larvae. Misuse of these chemicals for killing fish in streams and rivers is also practised. However, the types, quantities and usage pattern of OCPs vary across the region.

About 2500 tonnes of OCPs mostly DDT, toxaphene and endosulfan were used annually on cotton plantations in the 1970s in Sudan (Elzorgani *et al.*, 1979). More than 3500 tonnes of DDT were used on cotton plantations in Uganda between 1965 and 1972 (Dejoux, 1988). In Côte d'Ivoire in 1976, about 600 tonnes of lindane were used for cocoa and 320 tonnes of DDT were applied on cotton. In 1981, about 350 tonnes of lindane, dieldrin, heptachlor and endrin were used for timber protection. In Zimbabwe, about 300 tonnes of DDT applied at the rate of 2-3 kg/ha were used in agriculture between 1981 and 1982. In Burkina Faso, in Houndé-Dédougou region, 30 tonnes of DDT and 30 tonnes of endosulfan annually were used on cotton.

In the areas north of the Sahara (Mauritania, Mali, Niger and Sudan), the control of desert locusts for several years was by OCPs (dieldrin and lindane). Limited amounts of dieldrin were still used during 1986-1988 while presently organophosphates are used which are less persistent than the OCPs (FAO, 1988).

Ground spraying and aerial application of OCPs especially DDT, dieldrin and endosulfan to control vectors for human and livestock diseases are also an important source of contamination of aquatic ecosystems. Since 1944, DDT had been used largely for black fly larvae control (Simuliidae) in many regional programmes in Africa. About 60 tonnes of DDT were used annually in the continent to control Simuliidae from 1966 to 1970 (Dejoux, 1988). Tsetse fly control and eradication programmes involving the spraying of DDT, dieldrin and endosulfan have taken place in different parts of the region over the last 20 to 30 years as well (Dejoux, 1988).

These applications of OCPs cause the accumulation of their residue in the environment of the application area which is of ecological and public health concern. The main anthropogenic sources of these substances into the aquatic environment are:

- (i) Deliberate application e.g. spraying of pesticides to eradicate trash fish, and control aquatic weeds, snails and insects.
- (ii) Dumping of wastes/containers from public health, agricultural and industrial usage.

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- (iii) Domestic and industrial effluents - effluents from pesticide manufacturing or formulating industries or industries using CLHCs, e.g. textile factories, food industry and thermal power plants.
- (iv) Accidental spillage from agricultural and industrial sites, road and rail vehicles and ships.
- (v) Drainage and run-off from treated farm lands, garbage and industrial solid wastes dump.
- (vi) Dumping of sawaga sludga, municipal and industrial solid wastes.
- (vii) Atmospheric input e.g. in dry deposition and wat precipitation; burning or/and incineration of domestic, municipal or industrial solid wastes; industrial emissions e.g. through vaporisation of paints, varnishes, lacquers etc.

The relative importance of the foregoing point and non-point sources of pollution by CLCHs depends on the aquatic system under consideration (Table I). Spray contamination by drift, drainage and agricultural run-off as well as domestic/industrial effluents are significant point- and non-point (diffuse) sources of pollution of lakes/ponds, streams/rivers and coastal waters/estuaries. For CLHCs, atmospheric input seems to be the major source of oceanic pollution compared to land-based sources (GESAMP, 1989).

Table I
Relative importance of sources of chlorinated hydrocarbon pollution
for diffarant aquatic systems (From Edwards, 1977. © Plenum Press, New York)

	Spraying	Run-off	Effluents	Atmosphere
Lakes/Ponds	+	+	-	+
Streams/Rivers	+	+	+	+
Estuaries	+	+	+	+
Oceans	-	+	+	+

Co-disposal of industrial, municipal, domestic and medical wastes in open dumps, or non-sanitary landfills or open burning is commonly practised. Though these waste disposal methods may be cheap and convenient, they are not environmentally safe and sound and therefore not acceptable. Leachate from open dumps and landfills (Shuster, 1976; Arebun, 1990), are therefore recognised also as sources of CLHC pollution of surface and ground water.

A recent report (UNEP/FAO/WHO/IAEA, 1990) indicated that land-based sources contribute a total input of organochlorine pesticides estimated at about 90 tonnes/annum to the Maditerranean Sea; information for PCB loads is not available. Similar exercises are

in progress in the WACAF and EAF sub-regions especially as some CLHCs such as PCBs, DDT and dieldrin have become global pollutants due to (a) their volatilisation from the sites of application; (b) atmospheric transport and deposition and (c) transport via rivers and ocean currents (Eisenreich *et al.*, 1979; Croll, 1991).

3. FATE OF CLHCs IN THE AQUATIC ENVIRONMENT

On entry into the aquatic environment through various pathways, these non-polar, toxic, semi-volatile and fairly persistent substances may remain within the water body unchanged for a period of time, undergo degradation to simpler compounds which may be more toxic or/and more persistent than the parent compounds (e.g. DDE, dioxin) or get reversibly transferred into the atmosphere by volatilisation, Fig. 1 (Edwards, 1977; Keith, 1976).

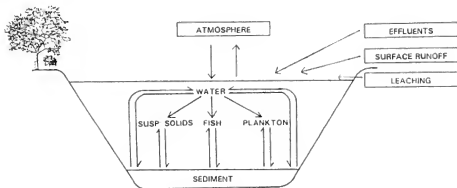


Fig.1 Pathways and movement of chlorinated hydrocarbon substances in the aquatic environment. (Adapted from Edwards, 1977)

The ultimate fate of these pollutants including partitioning into various aquatic environmental compartments (water, suspended solids, sediments and biota), will depend on a number of factors including: concentration, dilution, water solubility, biogeochemical processes taking place, adsorption to soils, suspended particulates and sediments, lipophilicity, and bioaccumulation in living organisms (Khan, 1977).

The hydrophobic nature of CLHCs makes their presence in water to be at ultra-trace level (ng/l) and their accurate determination difficult. The adsorption of these compounds to particulate matter and sediments is an important mechanism for their removal from the water column. Consequently, the sediment component of aquatic ecosystems can be ultimate sink of CLHCs similar to metals (see pages 32 ff of this publication) and petroleum hydrocarbons (Adekambi, 1989); suspended particulates entering slow moving waters

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such as larger water bodies settle out, and their associated CLHCs are added to the existing sediments component.

Being hydrophobic, CLHCs have a high potential for bioaccumulation in aquatic plants, fish and shellfish and undergo bio-magnification along trophic levels (Vandenbroek, 1979; Osibanjo and Bamgbose, 1990). The bioaccumulation potential of CLHCs can be predicted based on the 1-octanol/water equilibrium partition coefficient values, i.e. Kow values (Karichhoff *et al.*, 1979; Mackay, 1982; Gossett *et al.*, 1983 with log Kow values ranging from 3.8 to 6.9. The accumulation of these recalcitrant CLHCs in birds and mammals feeding on contaminated aquatic biota may occur which can then result in their transport over great distances (migratory birds, fish and mammals).

Air has been recognized as an important medium of long-range transport of these substances (GESAMP, 1989).

4. ECOLOGICAL AND PUBLIC HEALTH IMPACT OF CLHCs IN THE AQUATIC ENVIRONMENT

The organochlorine pesticides (OCPs), e.g. DDT, dieldrin and industrial chemicals like PCBs, their metabolites or conversion products have been reported to be ecologically harmful and toxic to humans as well. The acute toxicity of OCPs to aquatic organisms has been become evident in the past by significant fish kills associated with the accidental release of DDT, toxaphene, dieldrin, aldrin and heptachlor into the aquatic environment (Eichelberger and Lichtenberg, 1971; Heydorn, 1970). Nowadays, contamination of water with these recalcitrant chemicals often results in bioaccumulation in fish and other biota, sometimes to biologically active levels. Hence, these chemicals have been suspected to be cancer causing agents in fish and other aquatic organisms (GESAMP, 1991).

Residues of these toxic chemicals found in water, sediments, fish and other aquatic biota can pose a risk to aquatic organisms, to predators and to humans. In order to minimise health risk from the ingestion of food contaminated with these chemicals, environmental protection agencies and public health authorities including WHO have set Maximum Residue Levels (MRL) or Maximum Allowed Concentrations (MAC) for CLHCs in water, fish and shellfish. (Smeets and Amavis, 1981; Walter and Graham, 1988; UNEP/FAO/WHO, 1988)

Fish eating birds are at risk of population decrease and even of extinction, as a consequence of reproductive failures resulting from eating aquatic organisms contaminated with these chemicals. This is because CLHCs can cause egg shell thinning or impair the process of formation of the egg shell of several species of birds by interfering with the deposition of calcium (Trape, 1985; Matthiessen and Roberts, 1982; Koeman *et al.*, 1978).

5. ANALYTICAL METHODS FOR CLHC ANALYSIS IN AQUATIC ENVIRONMENTAL SAMPLES

Chlorinated hydrocarbons are present at parts per trillion level (ng/l) in water samples and at parts per billion or parts per million levels (ng/g or µg/g) in sediments and

biota, thereby requiring highly specific, sensitive and reliable analytical methods for carrying out such trace and ultra-trace measurements.

The basic analytical steps involve (Roberts, 1985; Alford-Stevens, 1986):

- (i) Sample collection and preparation;
- (ii) Extraction or removal of the compounds of interest from the sample matrix into one that can be analyzed;
- (iii) Clean-up of extracts or enrichment of the concentration relative to that of other sample components;
- (iv) Separation or isolation of extracted components;
- (v) Determination (preceded by derivation, if necessary);
- (vi) Identification of positive residues and measurements of compounds of interest.

Since these compounds are non-polar, the use of single solvents, e.g. hexane, dichloromethane, or binary mixtures of non-polar and polar solvents (e.g. hexane + diethylether; hexane + acetone, hexane + isopropanol, hexane + benzene) is employed to extract these compounds from aquatic environmental samples, namely water (APHA/AWWA/WPCF, 1985; Kahanovitch and Lahav, 1974; Nwankwoala and Osibanjo, 1992), sediments (El-Dib and Badway, 1985; Jensen *et al.*, 1977; Frank *et al.*, 1977) and fish (Jensen *et al.*, 1972; UNEP/FAO/IOC/IAEA, 1986; Haahti and Perttälä, 1988).

The need for sample extract pre-concentration of CLHCs results from the fact that the detection system of the analytical instrument may not have the necessary selectivity, sensitivity or freedom from matrix interferences. It also offers analytical isolation as well as enrichment factors.

Most pre-concentration techniques fall into two classes:

- (i) Solvent extraction followed by solvent reduction, or
- (ii) Sorbent trapping with subsequent elution or thermal desorption.

The Rotary Evaporator and the Kuderna-Danish concentrator with Snyder Column have been widely used for solvent reduction (UNEP/FAO/IOC/IAEA, 1986; Nwankwoala and Osibanjo, 1992).

A simple method for sample clean-up after solvent reduction is the use of acid-base (Waliszewski and Szymezynski, 1982; Haahti and Perttälä, 1988) depending on the stability of the analytes to this treatment. Another common method of sample clean-up involve the use of adsorbents: macro-reticular resins, polyurethane foams, activated carbon, Tenax-GC, Silica gel, Florisil, alumina (Keith, 1976, UNEP/FAO/IOC/IAEA, 1986) because of the difficulty in separating DDT and metabolites from PCBs (Armour and Burke, 1970).

Gas chromatography with electron capture detector (GC-ECD) using single or mixed stationary phases on a packed glass column or a single phase on a glass or quartz high resolution capillary column, is the major technique used for the determination of chlorinated hydrocarbon compounds in environmental samples (Alford-Stevens, 1986; UNEP/FAO/OC/IAEA, 1986; Sarker and Sen Gupta, 1988; Cairns and Siegmund, 1981).

In recent years, the use of GC-mass spectrometry (GC-MS) especially in the selective ion monitoring mode (SIM) has proffered the most selective and sensitive detector for the simultaneous determination and confirmation of CLHCs (Alford-Stevens, 1986; Roberts, 1985).

Apart from the dearth of competent experts in trace CLHCs determination in environmental samples, the choice of analytical methods for CLHCs in the African region has been influenced largely by the restricted availability of materials, apparatus and functional modern selective and sensitive equipment, underscored by the desirability of obtaining accurate analytical data with reasonable cost-effectiveness. Consequently, most of the CLHC determinations in the region have been carried out by packed column gas chromatography with ⁶³Ni electron capture detector.

6. OVERVIEW OF CHLORINATED HYDROCARBON DISTRIBUTION IN AFRICA

6.1 North Africa

Organochlorine pesticides, especially DDT and its derivatives were the first generation of chlorinated hydrocarbons to be used for control of agricultural pests and human diseases (vector control) in the North African sub-region since the 1950s.

The River Nile and the main irrigating and drainage canals, ending directly or indirectly via coastal lagoons into the Mediterranean Sea, are the main sources of pesticide contamination of the Egyptian coast.

The limited information available in the sub-region is based largely on studies that have been carried out since the late 1970s in Egypt on the residual levels of CLHCs in different environmental compartments of inland and coastal water bodies. El-Sebae and Abu-Elamayem (1979), in one of the earliest studies on the River Nile, the connected canals and drainage systems reported the detection at quantifiable levels of lindane, heptachlor, *o,p'*-DDT and *p,p'*-DDT at concentrations ranging from 100-950 ng/l in all the water samples. The relatively low levels of chlorinated insecticides in the Mehmodiah Canal (drinking water source for Alexandria) and the waste water might be due to the cessation of use of this group of insecticides in Egypt since 1971 because of their persistence.

Saad *et al.* (1985) analyzed composite sediment samples taken in 1968 from Lake Manzalah and in 1970 from Lake Mariut and Nozha Hydrodrome for DDT and PCBs. Lake Manzalah, the largest of the Nile delta lakes, receives drainage water contaminated with pesticides and fertilizers from a much larger agricultural area than Lake Mariut which is also polluted by sewage and industrial wastes. The Nozha Hydrodrome was separated artificially from Lake Mariut in 1939 and is fed by contaminated Nile water. While Lake Mariut and Nozha Hydrodrome showed relatively low levels of total DDT (29.8 and

54.1 ng/g respectively), Lake Manzalah was heavily polluted with 877 ng/g. PCB levels were 17.8, 21.4 and 71.2 ng/g respectively (Table III). The total DDT/PCB ratio was in all three lakes much greater than 1, indicating agricultural inputs of DDT rather than industrial discharges as the main source of pollution by organochlorine compounds.

During 1978/79 Lake Mariut and Nozha Hydrodrome were revisited and analyses done for organochlorines in water by Saad *et al.* (1982) and in sediments by Abu-Elamayem *et al.*, (1979). The major substances detected in water of Lake Mariut were lindane, *p,p'*-DDE, *o,p'*-DDT and *p,p'*-DDT, with mean residue values of 2,091, 4,493, 9 and 134 ng/l, respectively (Table II). Since sediments are sinks for pollutants, much higher values were found compared to the levels in water. Mean values reported for the Lake Mariut sediments were 89.1 (lindane), 768.0 (*p,p'*-DDE), 19.3 (*o,p'*-DDT) and 86.3 (*p,p'*-DDT) ng/g dry weight respectively (Table III). Contamination levels in fish were 34.98 ng/g (lindane), 38.96 ng/g (*p,p'*-DDE), 17.36 ng/g (*p,p'*-DDT) and 60.76 ng/g (total DDT) (Table IV). In Nozha Hydrodrome, lindane, *p,p'*-DDE and *p,p'*-DDT were detected in its water and sediments. The mean concentrations of these compounds found in water were 1,100 (lindane), 1,540 (*p,p'*-DDE) and 600 (*p,p'*-DDT) ng/l. Values for the Hydrodrome sediments were 119.5 (lindane), 840.4 (*p,p'*-DDE) and 91.0 (*p,p'*-DDT) ng/g dry weight.

Saad (1981) reported concentrations of organochlorine pesticides in water, sediment and fish in Lake Mariut and the Nozha Hydrodrome for the following two-years period (1979-81). The mean concentrations of total DDT (21,440 ng/l) found in the water of Lake Mariut was markedly higher than that in the Hydrodrome water (13,610 ng/l), reflecting the effect of pollution with DDT compounds on Lake Mariut resulting from huge discharges of agricultural drainage waters. *o*-HCH, lindane, *o,p'*-DDE, *p,p'*-DDE, *o,p'*-DDT and *p,p'*-DDT were found in Lake Mariut water with mean values of 120, 1,310, 1,380, 6,630, 2,690 and 9,820 ng/l respectively (Table II). The concentrations of pesticides in fish samples were higher than those in the lake water; mean values for *o*-HCH, lindane, *o,p'*-DDE, *p,p'*-DDE, *o,p'*-DDT and *p,p'*-DDT were 2.03, 80.06, 29.0, 10.1, 9.3 and 31.8 ng/g respectively. The mean value of total DDT was 84.5 ng/g (Table IV). Fish from the Hydrodrome were found to be less contaminated. The detected pesticides in Lake Mariut sediments were *o*-HCH, lindane, *p,p'*-DDE, *o,p'*-DDT and *p,p'*-DDT, with average values of 65.5, 327.0, 1,672.8, 82.8 and 270.5 ng/g dry weight, respectively (Table III). In the Hydrodrome sediments, only lindane and *p,p'*-DDE were found, with mean values of 423.5 and 456.0 ng/g, respectively. The pesticide levels in the lake sediments were much higher than those in the lake water and fish.

Tayel (1981) investigated the seasonal distribution of chlorinated pesticide residues in the water and fish of Abu-Kir Bay (Mediterranean Sea). The mean concentration found in the water were 4.88, 18.05 and 24.26 ng/l for *o*-HCH, lindane and total DDT, respectively (Table II). These pesticides showed regional and seasonal variations in the bay, due to changes in meteorological conditions, discharges of freshwater from the Rosetta Branch of the Nile and of the brackish water from lake Edku, as well as due to industrial wastes from El-Tapia pumping station. These discharges are significant pollution sources for the bay. Residues of these compounds in the sediments of the bay gave values several times higher than the corresponding concentrations in the bay water: 0.09, 0.05 and 1.73 ng/g for *o*-HCH, lindane and total DDT, respectively (Table III). Analysis of six fish species in the bay showed the presence of *o*-HCH, lindane and total DDT in much higher concentrations compared to those in the bay water. Concentrations differed

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between various fish species and even within specimen of the same species, concentrations also varied seasonally and with body size and weight.

Ernst *et al.* (1983) monitored the levels of organochlorine compounds in various aquatic organisms from the Egyptian coastal area in the vicinity of Alexandria. DDT and its major degradation products, DDE and DDD, α -HCH, γ -HCH, dieldrin and PCBs were the major compounds detected. The results indicated that primarily the western coast of Alexandria seemed to be polluted with organochlorine compounds. With increasing distance from Alexandria towards Rosetta, the level of PCBs tended to decrease.

Macklad *et al.* (1984a) also monitored the levels and distribution of chlorinated hydrocarbons in some fish species from Lake Edku and Abu-Kir Bay. The data indicated that DDT and its metabolites (DDE and DDD), hexachlorocyclohexane (α - and γ - isomers), endrin and PCBs (as Aroclor 1260) were the major chlorinated hydrocarbons detected in fish from Lake Edku and in the region of lake-sea connection. DDE was the major DDT degradation compound detected. DDD was detected only in *Mugil*; its level in the lake-sea connection was higher than inside the lake, reflecting the effect of industrial pollution. Also, the levels of chlorinated pesticides in *Tilapia* species from the lake-sea connection were higher than those from this lake, again reflecting the effect of industrial pollution. PCBs such as Aroclor 1260 was detected for the first time in two fish samples from Lake Edku. Its level was positively correlated with the fat content of the fish. However, PCBs were detected more frequently in Abu-Kir fish samples than in those from Lake Edku. This indicated that the PCB pollution originated essentially from industrial wastes in Abu-Kir Bay.

Macklad *et al.* (1984b) monitored the levels of chlorinated pesticides in two fish species from Lake Mariut and the Nozha Hydromere. The data of these fish (*Mugil* and *Tilapia* species) indicated that DDT and its metabolites (DDE and DDD), HCH and endrin were the major chlorinated pesticides detected.

In the Hydromere fish, the level of γ -HCH was higher than the other detectable isomers α and β . DDE levels in *Mugil* species ranged from 3.13 to 822.0 and from 3.0 to 1,320.0 ng/g wet weight in fish muscles and liver, respectively. DDT is still detected in aquatic organisms although it was banned several years ago. Endrin was detected in all fish samples from the Hydromere. The bioconcentration factor for chlorinated pesticides in liver samples was higher than in muscles.

Also in fish from Lake Mariut DDE was the major degradation product of DDT, as in case of the Hydromere. DDD was detected in five samples. Generally, the levels of chlorinated pesticides in Lake Mariut fish were lower than in those from the Hydromere. Bioconcentration factors of these compounds in different organs of *Tilapia galilaea* increased from muscle over gonads to liver.

6.2 East Africa

The catchment areas of the East African lakes and the Indian Ocean are sites of intensive agriculture, urbanisation and industrialisation.

Most of the studies in this sub-region have been carried out in Kenya as part of the monitoring activities for the assessment of the ecological and human health impacts of pesticides application in agriculture and disease vector control activities. Only few cases of water and sediment analyses were reported. Most of the studies centre on analysis of biota and wild life samples.

Sudan

The only available studies outside Egypt concerning the accumulation of organochlorine insecticides in fish from the Gezira of Sudan (central Sudan) and Lake Nubia (southern 180 km stretch of High Dam Reservoir) are those of El-Zorgani (1976) and Elzorgani *et al.*, (1979), respectively.

In the Gezira Research Farm, 28 specimens representing 5 types of fish have been analyzed for residues of organochlorine insecticides (Table IV). All fish samples contained residues of *p,p'*-DDE, *p,p'*-DDD, *p,p'*-DDT and total DDT with mean values of 670, 1,470 and 2,950 ng/g fresh weight respectively (El-Zorgani, 1976). This high accumulation reflects the increasing use of organochlorine insecticides over the last 50 years in central Sudan, where the amounts largely exceeded 1000 tonnes/year of various organochlorine insecticides.

Muscle and liver tissues of twenty-nine fish specimens belonging to seven different species were collected and analyzed by Elzorgani *et al.* (1979) for DDT isomers and metabolites. Only 10 out of 58 samples analyzed were found to contain detectable levels of OCP residues. *p,p'*-DDE was found in all the ten samples (49 (3-153) ng/g fresh weight) while *p,p'*-DDT was found in only 3 muscle samples (8 (5-14) ng/g fresh weight). The range of total DDT in fish muscle was from 6-184 ng/g; the highest residue value of 184 ng/g was found in a muscle sample of a specimen of *Hydrocynus forskali* (Table IV). This fish was proposed as a suitable indicator species for monitoring OCPs in the aquatic environment. The most likely source of chemical contamination of Lake Nubia is the cotton growing region along the Blue and White Niles in central Sudan. In this area, the annual pesticide usage amounts to about 2,500 tonnes of mostly organochlorine compounds, especially DDT, endosulfan and toxaphene. Furthermore, the intensive application of pesticide in the Gezira and along the White Nile in central Sudan were implicated as the source of chemical contamination of the lake which could adversely affect the fish population, thereby endangering plans for the development of a fisheries industry in the area.

Tanzania

The use of pesticides in agriculture is not widespread (Alabaster, 1981). Cotton, sugar cane and coffee are grown near the northern shore of Lake Tanganyika which are aerially sprayed with pesticides at a rate of about 45 t/year. In the marine environment, DDT, endrin, aldrin, toxaphene and other pesticides reach the Indian Ocean via rivers and from the major towns of Dar-Es-Salaam, Tanga, Lindi and Zanzibar (Bryceson *et al.*, 1990).

Paasivirta *et al.* (1988) described the results of chlorinated insecticide and PCB residues analysis of six sediments samples, two aquatic plant samples (leaves and roots

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of *Pistia stratiotes*) and one fish (*Tilapia*) from a small man-made lake, Nyumba ya Mungu Reservoir in Tanzania. PCB was not detected in any sample. Three insecticides, DDT and its metabolites DDE and DDD, lindane and dieldrin were detected and quantified. Mean concentrations found in sediments were for DDE and DDD 1 ng/g, for DDT 3 ng/g, for lindane 1 ng/g, for dieldrin 4 ng/g and for Tanzadrin, a photometabolite of dieldrin, 131 ng/g (Table III). The fish sample contained (per gramme dry weight) 14 ng DDE, 4 ng DDD, 6 ng DDT, 3 ng lindane, 10 ng dieldrin and 11 ng Tanzadrin (Table IV). Mean values in aquatic plants per gramme dry weight were 15 ng DDE, 18 ng DDT, 4.5 ng lindane, 27 ng dieldrin and 25 ng Tanzadrin (Table VI).

Burundi

The principal use of pesticides in Burundi is on crops grown in the plains of the Ruzizi River (Autrique, 1977). The river drains into the northern, shallow part of Lake Tanganyika. Samples of fish have been examined in 1971 and 1972 for pesticides (Deelstra *et al.*, 1976; Alabaster, 1981). The flour made from dried fish was analyzed and quantities of DDT and DDE combined were estimated at 700 ng/g in *Limnothrissa*, 750 ng/g in *Stolothrissa*, and 380 ng/g in young *Luciolates*. The total quantity of DDT and its metabolites varied in whole dried fish between 450 and 2,390 ng/g. Seasonal variation was apparent, showing a maximum during the dry season after the cotton harvest. Apart from this, the quantities decrease with distance from the opening of the Ruzizi plain at the inflow to the lake.

Uganda

In Uganda, pesticides have been used to protect cash and food crops and thus increase their yield (Bugenyi, 1984). The application of pesticides has been mismanaged by the locals with the consequent threat to the aquatic environment due to lack of advice on the safe use and disposal of pesticides. The quantity and concentration of pesticides used is unknown (Bugenyi and Balirwa, 1989). They are mainly applied as aerosols, smokes, sprays, paints, tree injections and granules. On the Victoria Nile, weekly treatments of 0.4 mg/l DDT was used to control blackfly larvae, *Simulium damnosum* (Corbet, 1958); in the Mount Elgon region in Uganda, however, DDT also killed predators of *Simulium* (Hynes and Williams, 1962). Sserunjogi (1974, 1976) determined dieldrin in Ugandan lakes (Nakiviri, Mburo, Kazuma, Kachera, Kyesama, Mishara, Karunga, Itara and Kijanebarora). In fish fillet dieldrin was found at levels between 2 and 27 ng/g fresh weight with a mean of 5, while in sediments (semi-dried on blotting paper) the range was 2 to 39 ng/g with a mean of 10 and in plants (water cabbages and water lilies) the range was 1 to 180 ng/g fresh weight with a mean of 21 ng/g (Tables III, IV and VI).

Malawi

Pesticides are mainly used on cotton grown along the shore of Lake Malawi and on tobacco, maize and tea grown in the Shire Valley (Alabaster, 1981). Between 1973 and 1978 fish from the Shire Valley were sampled and analyzed for DDT (Pickering *et al.*, 1980). Concentrations of DDT and its metabolites in fish muscle were below 50 ng/g but were relatively high in the ovaries of *Clarias gariepinus* (2,700 ng/g).

Kenya

The use of pesticides in Kenya dates back to 1946 when DDT was used in aerial spraying for control of mosquitoes in the Lake Victoria region.

Approximately 5,000 tonnes of pesticides/year are used on coffee, maize, cotton, wheat, tea, sugar cane, horticultural crops and for insect control (Mbote, 1979). Details of specific pesticides can be found in Calamari *et al.* (1994). Pesticides and their metabolites have been found in water and aquatic organisms including fish (Koeman and Pennings, 1970; Koeman *et al.*, 1972; Kallqvist and Meadows, 1977; Greichus *et al.*, 1978b; Lincer *et al.*, 1981; Mitema and Gitau, 1990; Mugachia *et al.*, 1992b). There is concern that concentrations are approaching levels that may have adverse effects (Alabaster, 1981).

Studies on pesticides in Kenya's aquatic environment focused on the Rift Valley lakes, Lake Victoria and its catchment area, Athi and Tana rivers and the Indian Ocean. Van Someren (1950) reported massive fish kills in Lake Victoria following aerial spraying of DDT to control mosquitoes. Koeman *et al.* (1972) reported pesticides used in tsetse fly control treatments around Lake Victoria, where *Tilapia*, *Alestes*, and *Clarias* muscles had levels of 14 to 60 ng/g of dieldrin, and 10 to 25 ng/g of DDE (Table IV). Fish eating birds (kingfishers and cormorants) were contaminated via the food chain and contained 10 ng/g of dieldrin and 60 to 260 ng/g of DDE. Greichus *et al.* (1978b) detected DDE, DDD, dieldrin, DDT and PCBs in water, sediments and fish from Lake Nakuru. Very low levels of organochlorine pesticides were found in *Tilapia grahami*.

Munga (1985) also studied DDT and endosulfan residues in fish from Hola irrigation scheme in the lower Tana River basin where the pesticides were used for the control of cotton and maize pests. The concentration of residues varied according to the distance of the sampling site from the cotton fields, with fish closest to the site being the most contaminated. Fish samples from the Tana river itself were found to be least contaminated with pesticide residues. Of the four fish species studied, *Clarias massambicus* (= *C. gariepinus*), a bottom feeding species, had the highest mean concentration of residues in muscle tissue, 400 ng/g fresh weight of total DDT and 110 ng/g fresh weight of endosulfan (Table IV). Strong correlation of pesticide residues in muscle tissue with fat content was found.

Lincer *et al.* (1991) found that the main use of pesticide use in the Rift Valley region was in urban centres for mosquito, weed and rodent control, dog washes, stored grain protection and household pest control. DDE residues were detected in fish from Lakes Naivasha, Nakuru and Baringo at levels from 7 to 143 ng/g dry weight (Table IV); one predatory fish from Lake Baringo showed the highest level of DDE with 2,130 ng/g dry weight. Kanja (1988) estimated total DDT levels ranging from 31 to 367 ng/g in fish from Lake Victoria; HCH, lindane and dieldrin were also detected with levels ranging from 1.3 to 123 ng/g. Mitema and Gitau (1990) found in Nile perch (*Lates niloticus*) from Lake Victoria total DDT levels ranging up to 4,510 and 460 ng/g in fat and fillet respectively. Residues of lindane, aldrin, dieldrin and α -HCH were also detected (Table IV).

Mugachia *et al.* (1992a, 1992b) detected DDE, DDD, DDT, HCH, heptachlor and lindane in fish from Lake Naivasha, Rivers Athi and Tana and from the Indian Ocean, and found residue levels higher than those reported in other Kenyan studies. The mean total

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DDT level found in sharks was 702 ng/g (highest value: 3,415 ng/g); residue levels of the HCH group ranged from 4 to 290 ng/g. DDT in freshwater fish ranged from 52 to 11,125 ng/g. The highest DDE level measured was 220 ng/g. Lindane levels ranged from 3 to 295 ng/g, α -HCH from 9 to 21 ng/g (Table IV).

Greichus *et al.* (1978b) detected PCBs in Lake Nakuru, the most widely studied surface water in the country. They reported concentrations in water of <1 ng/ml, in sediments of <20 ng/g dry weight and in fish of <500 ng/g dry weight (Tables II-IV).

A preliminary risk assessment for pesticides used in the Lake Victoria catchment area was done by Calamari *et al.* (1994). They concluded that most pesticides used in the area may not create toxicity problems and do not bioaccumulate in the lake biota; only a few of them like aldrin have a potential for bioaccumulation. DDT found in fish tissues was low in concentration and is not of recent origin.

6.3 West and Central Africa

Many chlorinated insecticides have been used in this sub-region for over three decades in agriculture, vector control and public health; data on quantities are not readily available. Chlorinated hydrocarbons have been detected and quantified in different compartments, i.e. water, sediments, plants and fish, only in Nigeria and Côte d'Ivoire; in other countries of the sub-region studies of CLHCs have concentrated mainly on fish and shellfish from coastal waters.

Nigeria

Nigeria is the most populous country in Africa, with fairly active agricultural and vector disease control activities involving the use of chlorinated pesticides. It is the most industrialised country in the sub-region with about 70% of the manufacturing industries including electric power generating stations, petroleum refineries, pulp and paper mills, located in the coastal zone.

Agunloye (1984) and Tongo (1985) studied the occurrence and levels of chlorinated hydrocarbons in water of 17 rivers, 2 lakes and one dam in southern Nigeria. The overall range of values (ng/l) of the major CLHCs found were: lindane ND-167, aldrin ND-190, endosulfan ND-750, HCB ND-9.2, heptachlor ND-96 and PCBs ND-8991 respectively. DDT and metabolites have not been detected. Table II indicates the levels of these substances in some specific rivers. For example, concentrations (ng/l) in River Ogun which traverses three states and discharges into Lagos Lagoon were: lindane 1.4-41.9 (13.3), aldrin 5.1-49 (40), endosulfan ND-260 (116), heptachlor ND-0.8 (0.25) and PCBs ND-224 (87) respectively.

Ogunlowo (1991) studied the occurrence and levels of CLHCs in 9 rivers in Ondo State, a major cocoa growing area of Nigeria. He detected (in ng/l): lindane ND-6.4 (2.4), heptachlor ND-5.0 (2.1), endrin ND-21 (5.1), aldrin ND-3.5 (1.0) and dieldrin ND-2,150 (1,062). PCBs, DDT and metabolites were not detected (Table II).

Nwankwoala and Osibanjo (1992) reported the detection of 10 CLHCs residues including PCBs in surface waters in Ibadan, the largest city in the sub-region. The concentration ranges in ng/l of some of the compounds quantified are α - and β -HCH 1-302, lindane 7-297, aldrin ND-40, dieldrin 17.8-657, endrin ND-19, heptachlor 4-202, endosulfan ND-430, HCB ND-92 and total DDT ND-1,266; PCBs were detected but not quantified (Table II). These results show higher loads of CLHCs in the water bodies compared to concentrations elsewhere. This study confirms that organochlorine pesticide residues are widely distributed in the surface waters studied, even at sites remote from point sources.

Okonna (1985) showed the presence of pesticide residues in Lagos Lagoon water, concentrations in ng/l were: lindane 85.3; aldrin 19.3; DDE 12; HCB 1.9; endrin 12.5 and dieldrin 28.0.

Sunday M. (1990) analyzed 20 sediments samples from streams and rivers in Ibadan city, Oyo State. The concentration range (mean) in ng/g dry weight were: dieldrin ND-6 (1.4), α -HCH ND-1.6 (0.2), γ -HCH ND-2 (0.3), aldrin ND-0.04 (0.002), DDE ND-50 (6.8) and PCB ND-14 (1.8); heptachlor, endosulfan and endrin were not detected (Table III).

Ojo (1991) investigated the occurrence and levels of CLHCs in 23 bottom sediment samples from Lekki Lagoon in Lagos State. Eleven organochlorine pesticides and HCB were detected. PCBs were not detected (Table III). The ranges of concentration with means parenthesis, reported in ng/g dry weight were: lindane 0.11-4.9 (1.1), aldrin ND-347 (56), p,p' -DDE 11-555 (263), α,p' -DDD ND-348 (88), endosulfan 7-1,155 (301), heptachlor ND-1845 (64), β -HCH, ND-260 (66), α -HCH ND-116 (18.6), HCB ND-3.3 (0.4), endrin ND-129 (16.5), dieldrin 190-8,460 (4,560). Compared to other parts of the world, the sediments of Lekki Lagoon are to be considered fairly contaminated with organochlorine pesticides.

Fish samples from fresh water were found to contain significantly higher concentration of these chemicals than sediments and water. Amakwe (1984) detected 10 organochlorine pesticides, HCB and PCBs in 40 freshwater fish samples collected from various locations in Oyo and Ogun State. The relative occurrence of some of the CLHCs identified were lindane 100%, PCB and endosulfan 97%, DDT and metabolites 75%. The concentration ranges with mean in parenthesis in ng/g fresh weight were (Table IV): lindane 7-106.0 (25.6), p,p' -DDE 2.0-30.0 (3.4), p,p' -DDD 2.0-60.0 (7.8), p,p' -DDT 3.0-18 (2.9), total DDT 3.3-161 (20.6), PCB (Aroclor A1250) 8.0-130 (28.7), heptachlor 1.0-300 (50.0), endosulfan 3-904 (173), HCB 9.0-130.0 (12.7) and α -HCH 0.2-5.0 (1.3). Fayomi (1987) also detected and quantified 9 OCPs in south-eastern Nigeria. The relative occurrence of some of these compounds were PCBs, aldrin, lindane, and α -HCH 100%, endosulfan, δ -HCH, p,p' -DDD, p,p' -DDE and heptachlor 44.4%, 16.7%, 33.3%, 61.1% and 72.2% respectively. The concentration ranges with means in parenthesis in ng/g fresh weight were: α -HCH 0.2-7.4 (1.8), lindane 0.6-13 (4.4), heptachlor ND-1.0 (0.3), aldrin ND-14.9 (5.5), endosulfan ND-89.6 (141), p,p' -DDE ND-4.2 (1.8), DDD ND-8 (0.7), and PCBs 0.7-14 (3.8).

Osibanjo and Bamgbose (1990) have reported contamination by CLHCs of Nigerian marine fish and shellfish, based on the analyses of 94 samples of 25 marine fish species over 1983 - 1985 and 14 samples of 7 shellfish species in 1987. The concentration

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ranges in ng/g fresh weight were found to be for HCB 0.04-9.48, lindane ND-5.30, endosulfan ND-4.95, DDT 0.15-18.6, aldrin ND-54.60 and for PCB 11.0-225 (Table IV). Fish contained higher concentrations of aldrin, heptachlor, HCB and lindane than shellfish, while the reverse was observed for DDT and PCBs. The concentrations of residues obtained were found to be lower than those reported in literature for industrialised countries. Furthermore, predator fish species were found to concentrate more residues in muscle tissue than plankton feeders. The DDT/PCB ratios were less than 1, indicating a predominance of industrial activities over agricultural activities as the source of contamination of the marine environment. The fish *Galeoides decadactylus* was proposed as a potential bio-indicator organism for chlorinated hydrocarbon pollution monitoring in the study area.

Thus, various compartments of the aquatic environment in Nigeria are greatly contaminated by several OCPs, PCBs and HCB.

Côte d'Ivoire

Marchand and Martin (1985) assessed the contamination of Ebrié Lagoon sediments with DDT and metabolites, lindane and PCB. The concentration ranges in ng/g dry weight were: lindane 0.5-19, DDE 0.2-149, DDD 0.2-803, DDT 0.2-354, PCB 2-213 (Table III). Two hot spots were highlighted: Biétry Bay and Marcory Bay which are highly polluted.

The analysis of surface sediments of bays from the urban area of Abidjan Lagoon (Kaba, in press) showed that these bays are polluted. Concentration ranges were (ng/g): α -HCH 0.01-13.4, lindane 0.07-19.81, β -HCH 0.32-157.32, δ -HCH 0.01-5.05, heptachlor ND-6.80, aldrin 0.07-62.1, dieldrin ND-125.75, endrin ND-15.06, total DDT 2.50-242.83, PCB 8.49-1,013.92 (Table III).

Fish caught by poisoning with lindane and fish contaminated with lindane (lethal dose 0.1 mg/l) in the laboratory were also analyzed. Concentrations of HCH found did not exceed international consumption standards for fish and fish products. Concentrations in the gills were higher than those in the guts, muscle tissue had the lowest concentrations.

Marine fish in Côte d'Ivoire have very low concentrations of organochlorine substances (Kaba, 1992). The ranges for the species analyzed (*Pagellus bellottii*, *Epinephelus aeneus*, *Cynoglossus canariensis*, *Pseudotolithus senegalensis*, *Sphyræna sphyræna* and *Panæus notialis*) were: lindane < 0.1-2.4, heptachlor ND-2.7, aldrin 0.1-3.9, dieldrin ND-2.1, endrin ND- < 0.1, total DDT 0.4-12.9 ng/g dry weight.

Cameroon

Available data on organochlorine compounds from Cameroon concern fishery products from the coastal waters between Cap Limbo (around Limba) and the River Wouri estuary and creeks in Douala (Mbi and Mbome, 1991, Mbome and Mbi, 1991; see Table V). The results obtained (ranges and means in ng/g fresh weight) are fish - lindane ND-7.31 (1.60), aldrin ND-13.3 (2.4), DDTs ND-393 (89.5), PCBs ND-983 (196); shrimp - lindane 0.28-1.76 (0.98), aldrin ND, DDTs 76-540 (244), PCBs ND-705 (342); oyster - lindane ND-5.3 (1.44), aldrin ND-12.0 (1.71), DDTs ND-181 (113), PCBs ND-716 (209).

The area studied is characterised by the presence of banana, rubber and palm plantations along the coastline, of a petroleum refinery around Limbe and intense industrial activities around the port of Douala. The Douala area is linked by creeks to Edeé (southeast), a town with an aluminium processing complex, a hydroelectric plant and a paper pulp factory (closed down 2 to 4 years ago). Samples from Douala account for most of the high values of organochlorine compounds, especially DDT and PCBs.

Benin, Sierra Leone and Gambia

In Benin, Soclo and Kaba (1992) reported the following mean concentrations in ng/g fresh weight for fish: HCB <0.016, lindane 0.10, heptachlor 0.02, eldrin <0.006, *p,p'*-DDT 1.86 (Table V).

Portmann *et al.* (1989) in their assessment of the state of the marine environment of West and Central Africa reported mean total DDT and lindane levels of 46 and 12.4 ng/g fresh weight respectively for fish from the coast of Sierra Leone.

From the Gambia, the mean concentrations of lindane in ng/g fresh weight (Jellow, 1988) were: fish 0.029, shrimp 3.07 and oyster 1.74. Concentrations for heptachlor were 0.15, 0.74 and 0.18 ng/g respectively (Table V).

The low levels of CLHCs in marine organisms are probably due to the relatively low amounts of such substances used in these West African countries, compared to other developing countries.

6.4 Southern Africa

This Sub-region has a long history of chlorinated pesticides usage in agriculture, public health and disease control programmes. Two countries in the region, Zimbabwe and South Africa have heavy concentrations of primary and tertiary industries which could severely stress the aquatic ecosystem.

Zimbabwe

Greichus *et al.*, 1978a reported the detection and quantification of chlorinated hydrocarbons including PCBs in different environmental compartments of Lake Mchweine, Zimbabwe, with concentrations in fish being much higher than in sediments and water respectively. The concentrations found were for PCBs <1,000 ng/l in water, 120 ng/g dry weight in sediments and 1,200-2,300 ng/g dry weight in fish, for total DDT <100 ng/l in water, 57 ng/g dry weight in sediments and 180-450 ng/g dry weight in fish (Tables II-IV).

Matthiessen (1983) measured concentrations of DDT and metabolites in the environmental compartments of the principal rivers running into Lake Kariba. The values obtained were <20-300 ng/l in water, 40-740 ng/g wet weight in sediments, 170 ng/g fresh weight in fish muscle and 150-740 ng/g fresh weight in shellfish (Tables II-IV). Residue levels were also measured in fish liver (440 ng/g wet weight) and fish ovaries

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(360 ng/g fresh weight). According to the author, DDT contamination is due to the use of this pesticide for tsetse fly control.

Mhlanga and Madziva (1990) reported the concentrations of HCH, aldrin, dieldrin and total DDT in different matrices of Lake Mcllwaine. The values obtained (range; mean) were in fish (ng/g fresh weight): α -HCH ND-240 (64.1), aldrin ND, dieldrin ND-24 (1.33), total DDT (66.6), in water (ng/l): α -HCH 26-270 (100), aldrin < 10-120 (100), dieldrin 10-530 (200), total DDT 30-700 (400) and in sediments (ng/g fresh weight): HCH 2.0-42 (16), aldrin ND-12 (1.0), dieldrin ND-16 (5.0), total DDT 32-146 (76). No data was given for PCBs (Tables II-IV).

Botswana

Mathiessen *et al.*, 1982 have investigated the accumulation of endosulfan (highly toxic to fish with 24-h LC_{50} = 0.09-11.2 μ g/l depending on species and temperature) residues in fish and their predators, after aerial spraying for the control of tsetse fly in the Okavango Delta, Botswana. The maximum total residue concentration found in the muscle of living fish was 190 ng/g wet weight while the maximum found in whole dead fish was 1,500 ng/g. The residue levels in fish were approximately proportional to their fat content, with lean fish therefore being more susceptible to poisoning than fat fish. The lack of persistence of endosulfan in the Okavango aquatic ecosystem is demonstrated by the fact that residue levels in fish predators (fish-eating birds and crocodiles) were similar to their prey, the risk to them was consequently low.

South Africa

Concentrations and distributions of chlorinated hydrocarbon insecticides, PCBs and some metals were determined in bottom sediments, aquatic plants, aquatic insects, fish, fish-eating birds and their eggs from two South African lakes, Hartbeespoort Dam and Voëlvei Dam (Greichus *et al.*, 1977). Mean values reported for the Hartbeespoort Dam ecosystem were in fish (ng/g dry weight): dieldrin 80, p,p' -DDE 77, p,p' -DDD 100, p,p' -DDT 67, total DDT 244, PCBs 920, in water (ng/l): dieldrin < 100, p,p' -DDE 100, p,p' -DDD 100, p,p' -DDT 100, total DDT 300, PCBs 2,000 and in sediments (ng/g dry weight): dieldrin 2, p,p' -DDE 10, p,p' -DDD 18, p,p' -DDT 13, total DDT 45, PCBs 320. For the Voëlvei Dam ecosystem, the mean values were in fish (ng/g dry weight): dieldrin 27, p,p' -DDE 160, p,p' -DDD 20, p,p' -DDT 190, total DDT 370, PCBs 600, in water (ng/l): dieldrin < 100, p,p' -DDE < 100, p,p' -DDD < 100, p,p' -DDT < 100, p,p' -DDT < 200, PCBs < 1,000 and in sediment (ng/g dry weight): dieldrin < 1.0, p,p' -DDE 5.0, p,p' -DDD 2.0, p,p' -DDT 6.0, total DDT 13.0, PCBs 70.0.

Values for aquatic plants (water hyacinth and algae) are presented in Table VI. The insecticide residues most commonly found in both dams were DDE, DDD, DDT and dieldrin. Hartbeespoort had higher levels than Voëlvei of insecticides and PCBs in all types of samples common to both lakes, concentrations of PCBs having six or more chlorines increased with an increase in the trophic level.

7. LEVELS OF CLHCs IN DIFFERENT ENVIRONMENTAL COMPARTMENTS

Tables II to VI provide data on CLHCs in different compartments in the aquatic environment.

A panoramic view of the study sites pinpoint the fact that the investigation of the presence and quantitative estimation of CLHCs have centred on lakes, rivers and streams in agricultural pests control or disease vector control activity areas as well as in urban areas, some of which are industrialised. Since environmental impact assessment was non-existent prior to the application of these chemicals coupled with the significant contribution of atmospheric transport of these chemicals to distances far away from point(s) of application, most of the so-called baseline studies really represent post-impact assessment data. In other words, these studies provide apparent baseline data rather than the true baseline data expected from pristine environments.

7.1 Concentration of CLHCs in Water

There are gaps in data available on the levels of CLHCs in water (Table II). Most of the studies have been carried out to assess the ecological impact of specific groups of OCPs which have been used, in particular DDT and isomers, lindane, endosulfan, dieldrin, aldrin and heptachlor. Only in a few isolated cases industrial chemicals such as PCBs and HCBs have been determined. More data are available on inland than on coastal waters, especially from Nigeria and Southern Africa.

Generally, African inland waters are contaminated by a broad spectrum of OCPs. However, HCH, aldrin, endosulfan, *p,p'*-DDE, *p,p'*-DDT and total DDT were not detectable in many Nigerian inland water samples despite fairly large scale use of these chemicals. Perhaps in the hot tropical climate, volatilisation of these chemicals and atmospheric transport are responsible for the trace concentration of these chemicals in water. The concentrations in water can also be correlated with water solubility and persistence in water of these chemicals.

The OCPs with the lowest concentrations are generally heptachlor (ND-11) and HCB if we leave out single high values. Lake Mariut in Egypt appears the most polluted water body, based on exceedingly high values for γ -HCH (lindane) of 1,310 ng/l, for *p,p'*-DDE of 6,630 ng/l and for total DDT of 21,440 ng/l (Saad, 1981). Lake Nakuru in Kenya, Lake Mchlwaine in Zimbabwe and the South African reservoirs are contaminated by PCBs indicating pollution from industries as source of contamination. According to data from Nigeria (Tongo, 1985) and Egypt (Tayel, 1981) coastal waters are just as contaminated as freshwaters except for the Egyptian lakes which have very high values.

7.2 Concentration of CLHCs in Sediments

From the available data (Table III) relatively more information on a wide range of CLHCs has been reported for West Africa, in particular on aldrin, lindane, dieldrin, DDT and metabolites and PCBs. The table also shows that most freshwater sediments in Africa are contaminated with CLHCs. Except for high levels of DDT and metabolites (1.73-877 ng/g

dry weight), however, it can be inferred that in sediments of African inland waters contamination levels are low and therefore pose no ecological threat.

Coastal sediments exemplified by Abu Kir-Bay, Egypt are cleaner than inland water sediments. Lekki Lagoon, Nigeria, a semi-enclosed water body with several rivers draining into it provides a hot spot with very high mean values of some compounds, e.g. dieldrin (4,560 ng/g) and *p,p'*-DDE (263 ng/g dry weight). Another hot spot appears to be the Ebrié Lagoon, Côte d'Ivoire, which has a mean PCB value of 355.5 ng/g dry weight.

7.3 Concentration of CLHC Residues in Fish

Since CLHCs are lipophilic and can bioaccumulate in fish tissues, Table IV indicates that inland water fish are highly contaminated by DDT and metabolites and lindane which reflect the heavy usage of these chemicals. In particular fish from Kenyan rivers (Tana and Athi) and even more from the South African reservoirs are heavily contaminated with levels of 370 ng/g for DDT (Voëlvlei Dam) and 920 ng/g fresh weight for PCBs (Hartbeespoort Dam). Data for CLHCs levels in marine fish (Table V) are available only for West and Central Africa. In general, marine fish are less contaminated than freshwater species. Data for marine fish from Cameroon, however, show high values for DDTs and PCBs.

An attempt was made to identify trends of occurrence of DDT and its derivatives in fish fillet by looking at the data in Table IV. There is no clear trend towards decreasing concentrations over the years; however, lower DDT concentrations are more frequently detected in recent samples. This may be due to reduction in use and more stringent controls. This is also supported by the fact that differences in concentrations of DDT and its metabolites were wider in earlier studies which indicated recent use while they were much closer in later studies indicating past use. Furthermore, marine fish species appeared less contaminated than freshwater species as already indicated.

7.4 Concentration of CLHCs in Aquatic Plants

Only scanty data are presently available for levels of these chemicals in aquatic plants, since most studies of biota concentrated on fish.

Table VI reports quantifiable levels of *p,p'*-DDE for aquatic plants in Lake Naivasha, Kenya whereas trace to non-detectable levels were reported for Lake Nakuru, Kenya.

The ubiquitous water hyacinth which is now a menace in many African inland waters was found to give detectable and quantifiable levels in Nigerian coastal waters for dieldrin of 43, for lindane of 48.6, for heptachlor of 52 and for PCBs of 2,700 ng/g dry weight. Lower values of CLHCs were recorded for the plant in Hartbeespoort Dam, South Africa.

8. REGIONAL COMPARISON OF CLHC LEVELS

Based on the levels of dieldrin, lindane, endosulfan, total DDT and PCBs, water and sediments of the North African lakes in Egypt are more polluted, followed by West African rivers in Nigeria, the East and Southern African waters are the least polluted by these organic pollutants.

However, the trend for fish contamination is reversed. Fish from East Africa is more contaminated followed by fish from North Africa while fish from West Africa is least contaminated. This disparity may be linked to a number of factors including relative fat content in fish, fish size and feeding habits, as well as to bio-geochemical and abiotic transformations in different aquatic ecosystems.

9. COMPARISON OF CLHCs IN THE AFRICAN AQUATIC ENVIRONMENT WITH OTHER PARTS OF THE WORLD

In the GEMS/WATER programme report (UNEP/WHO, 1988), the absence of data on CLHCs levels in African waters was highlighted. The lack of data on the levels of these substances in coastal and marine fish was also underscored at a pollution monitoring workshop (IOC-Unesco, 1985). Nonetheless, this review indicates the presence and detection of all the substances mandatory for monitoring in GEMS/WATER during 1979-1984 with the exception of mirex.

Concentrations above 100 ng/l were found for γ -HCH, DDE and total DDT in Egyptian lakes, Ibadan streams, Nigeria (DDT only) and PCBs in Hartbeespoort Dam, South Africa respectively, indicating pollution by these chemicals. These results are similar to level of DDT reported in Colombia by GEMS/WATER and the γ -HCH values reported for some major rivers in the United Kingdom (Croll, 1969), Japan (Suzuki *et al.*, 1974) and India (Ramesh *et al.*, 1990). However, the majority of the African inland waters have γ -HCH concentrations below 10 ng/l which is the recommended guideline for the protection of freshwater aquatic life in Canada (Merriman and Metcalf, 1988), similar to the results reported for Niagara River, Canada (Oliver and Nicol, 1984).

Exceedingly high dieldrin levels of over 1000 ng/l were found in some Nigerian surface waters. The results are also similar to levels reported for dieldrin under the GEMS/WATER in Colombia and Malaysia respectively but exceed several fold the 4 ng/l guideline set for Canadian freshwater aquatic life.

The PCBs values of < 1,000 ng/l obtained for dams in South Africa, lakes in Kenya, Zimbabwe and South Africa as well as Awba Dam in Nigeria are comparable to the high values reported for United Kingdom, Thailand, China and Japan in the 1979-84 GEMS/WATER programme.

Apart from a few hot spots due to localised pollution problems, African inland water sediments are relatively unpolluted by CLHCs and the values obtained are in most cases lower than concentrations reported for developed countries (Eisenreich *et al.*, 1979, Oliver and Charlton, 1984).

Levels of CLHCs in fish from African waters are relatively low compared to values from other parts of the world and are similar to results obtained by GEMS/FOOD for 1984-1985 (UNEP/FAO/WHO, 1988), except in a few cases around pollution hot spots. Levels found are much lower than the permissible limits for CLHCs in fish for human consumption (Nauen, 1983; FAO, 1989).

10. REGULATORY CONTROL MEASURES

The occurrence of CLHCs in different compartments of the aquatic environment even at trace and ultra-trace levels should give cause for concern. Long-term exposure to sub-lethal concentrations of these substances through various pathways in the aquatic environment may cause far reaching ecological damage and health problems to man.

Institutional framework and regulatory mechanisms for the importation, transportation, storage, sale and application of these chemicals should be put in place in all countries. Reference is made to the International Code of Conduct on the Distribution and Use of Pesticides, adopted by the FAO Conference in 1985 and amended in 1989 (FAO, 1990). The objectives of this Code are to set forth responsibilities and establish voluntary standards of conduct for all public and private entities engaged in or affecting the distribution and use of pesticides, particularly where there is no or an inadequate national law to regulate pesticides.

11. CONCLUSIONS

The environmental impact of several decades of use of chlorinated hydrocarbons in Africa for multifarious purposes has been manifest in the contamination of different aquatic compartments with these substances, especially DDT and its metabolites, lindane, dieldrin and PCBs. The pattern of pesticide residues found in environmental samples based on the available data bears direct relationship to pesticides used in the continent.

This review has accomplished the difficult task of compiling data on CLHC levels in the aquatic environment of the region so far non-existent. The concentrations found in various aquatic environmental compartments, with few exceptions are lower than in other parts of the world, in particular in developed countries which have a longer history of high pesticide consumption and intense use. Generally, the coastal waters, sediments and biota are less contaminated than inland water environmental compartments, with the exception of a few hot spots.

The data available is limited and, therefore, forms a good basis for further monitoring work, involving more countries in the region. Nonetheless, the data on fish fillet are homogeneous and comparable, having been generated through coastal and marine pollution monitoring programmes and research studies initiated in the region in the 1980s under the aegis of the UNEP Regional Seas Programme. The data showed a tendency towards decreasing concentration of these substances over the years and a direct link with reduction in use and with more stringent controls on these classes of compounds by national governments.

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Nevertheless, the occurrence of these synthetic micropollutants in different compartments of the aquatic environment, even at trace and ultra-trace levels, is of ecological and environmental health concern. The regulatory framework and control on the use of these chemicals should be put in place in the countries of the region as well as enforcing the International Code of Conduct on their proper use.

Table II
Concentration of chlorinated hydrocarbons in African inland and coastal waters (ng/l)

Location/water type	Dieldrin	ppHCH	HCB	ppHCH (Unadvised)	Heptachlor	Aldrin	Endosulfan	Reference
INLAND WATERS								
North Africa - Egypt								
Lake Mariout		120		2091				Saad et al., 1982
Lake Mariout				1310				Saad, 1981
Najha Hydrodrome		<100		1100				Abu Elamayem et al., 1978
East Africa - Kenya								Kilgus and Mubwira, 1977
Lake Nakuru								
West and Central Africa - Nigeria								
Badan, Streams	250 (17.8-857)	150 (1-302)	17 (ND-92)	100 (7-297)	72 (4-202)	20 (ND-40)	98 (ND-430)	Newarkwada and Odujirin, 1982
River Ogun				13.3 (1.4-41.8)	0.26 (ND-0.8)	40 (5.1-48)	118 (ND-200)	Agudoye, 1984; Tenge, 1985
River Inu			1.0 (ND-5)	0.2 (ND-0.6)	4 (ND-11.4)	13 (ND-40)	13 (ND-41)	Agudoye, 1984; Tenge, 1985
Cross River			0.8 (ND-2.5)	0.3 (ND-1.1)	2 (ND-8.8)	38 (ND-143)	20 (ND-80)	Agudoye, 1984; Tenge, 1985
Akiba Dam, Badan				81 (8-187)	0.47 (ND-3.48)	18 (12-29)	20 (ND-30)	Agudoye, 1984; Tenge, 1985
Kang Lake	560			0.12 (ND-0.24)	3.3	0.85 (ND-3.05)		Adeniyi et al., 1981
R. Eru Dam, Ondo	740			2.0	ND	3.1	ND	Ogundimu, 1993
River Eru, Ondo	2150			2.0	ND	ND	ND	Ogundimu, 1981
River Osha, Ondo	1120			8.4	1.6	ND	ND	Ogundimu, 1981
R. Oshana, Ondo	1380			4.8	4.8	3.5	ND	Ogundimu, 1981
Southern Africa								
Hartbeespoort Dam, RSA	<100							Giesche et al., 1977
Vaal Dam, RSA	<100							Giesche et al., 1977
L. Mchwenze, Zimb.	<100							Giesche et al., 1978a
L. Malawi, Zimb.	200 (<10-530)	100 (28-270)				100 (4-120)		Mhlanga and Mafuvu, 1990
COASTAL WATERS								
North Africa - Egypt								
Abou el Bay		4.88		18.05				Tayel, 1981
West and Central Africa - Nigeria								
Lagos Lagoon	8 (ND-24)		2 (0.8-4.1)	182 (16-834)	ND	5.3 (3-190)	29 (ND-80)	Tenge, 1985

ND = Not detected

Table II (cont.)
Concentration of chlorinated hydrocarbons in African inland and coastal waters (ng/l)

Location/water type	p,p' -DDE	p,p' -DDD	p,p' -DDT	Total DDT	PCE	Reference
INLAND WATERS						
North Africa - Egypt						
Lake Mariut	4483		134	5100		Saad <i>et al.</i> , 1982
Lake Mariut	6630		9820	21440		Saad, 1991
Nasrta Hydrodrome	1540		600			Abu Elmagd <i>et al.</i> , 1979
East Africa - Kenya						
Lake Nakuru	< 100	< 100	< 100	13610	< 1000	Saad, 1981 Grachos <i>et al.</i> , 1978b Kallquist and Meadows, 1977
West and Central Africa - Nigeria						
Badam, Streams				310 (ND-1280)		Nwankwala and Dabanya, 1992
River Ogba					87 (ND-244)	Agbriye, 1994; Tonga, 1985
River Inio					121 (ND-241)	Agbriye, 1994; Tonga, 1985
Cross River					120 (ND-470)	Agbriye, 1994; Tonga, 1985
Awele Dam, Badam					330 (ND-1000)	Agbriye, 1994; Tonga, 1985
Kamp Lake				3.89 (ND-10.08)		Adeniyi <i>et al.</i> , 1991
River Eru Dam, Ondo	ND	ND	ND	ND	ND	Ogbinwa, 1981
River Eru, Ondo	ND	ND	ND	ND	ND	Ogbinwa, 1981
River Osa, Ondo	ND	ND	ND	ND	ND	Ogbinwa, 1981
River Owerri, Ondo	ND	ND	ND	ND	ND	Ogbinwa, 1981
River Agomu, Ondo	ND	ND	ND	ND	ND	Ogbinwa, 1981
Southern Africa						
Hartbeespoort Dam, RSA	100	100	100	300	2000	Grachos <i>et al.</i> , 1977
Vaal Dam, RSA	< 100	< 100	< 100	< 200	< 1000	Grachos <i>et al.</i> , 1977
Lake Kariba, Zimbabwe			< 20-3000			Martinez, 1983
Lake Kariba, Zimbabwe				350 (< 10-700)		Mitanga and Meadows, 1990
Lake Malawi, Zimbabwe	100	< 100	< 100	400 (10-700)	< 1000	Grachos <i>et al.</i> , 1978a Mitanga and Meadows, 1990
COASTAL WATERS						
North Africa - Egypt						
Abu-Kir Bay				24.3		Tayel, 1981
West and Central Africa - Nigeria						
Lagos Lagoon	3 (ND-15)	93 (ND-344)	ND	2500 (ND-9000)		Tonga, 1985

ND = Not detected

Table III
Concentration of chlorinated hydrocarbons in African inland and coastal water sediments (ng/g dry weight)

Location/water type	Dieldrin	α-CH	HCB	pHCH (Lindane)	Heptachlor	Aldrin	Endosulfan	Reference
INLAND WATERS								
North Africa - Egypt								
Lake Mariout		95.5		89.1				Abou Elmagasem <i>et al.</i> , 1979
Lake Maryout				327.0				Saad, 1991
Nasr El-Hydrodiurna				116.5				Abou Elmagasem <i>et al.</i> , 1978
Nasr El-Hydrodiurna				423.5				Saad, 1991
East Africa								
Lake Nakuru, Kenya	<1.0							Griechus <i>et al.</i> , 1978b
Lake Nyanda ya Mungu, Tanzania	4 (3.6)			1 (ND-4)		131 (ND-251) (translindane)		Pasovovic <i>et al.</i> , 1996
Lakes, Uganda	10 (2.38)							Saunstrup, 1974, 1976
West and Central Africa								
River Ogouma, Sudan, Nigeria	0.9 (ND-1.8)	0.7 (ND-2)		0.5 (ND-1.2)	ND	ND	ND	Sunday, 1990
River Oua, Sudan, Nigeria	0.3 (ND-0.5)	0.5 (ND-0.8)		ND	ND	ND	ND	Sunday, 1990
River Ouyere, Nigeria	2.0 (ND-6)	0.1 (ND-0.4)		0.9 (ND-2.0)	ND	ND	ND	Sunday, 1990
Lake Lagon, Nigeria	4560 (190-8460)	16.6 (ND-119)	0.4 (ND-3.3)	1.1 (0.11-4.9)	64 (ND-1845)	56 (ND-347)	30 (7-1155)	Op, 1991
Etouk Lagoon, Côte d'Ivoire	17.6 (ND-125.6)	3.3 (0.01-13.4)		2.3 (0.5-19)	0.9 (ND-5.8)	15.7 (0.07-62.1)		Marchand and Marin, 1995
Etouk Lagoon, Côte d'Ivoire				3.0 (0.07-19.8)				Koko, <i>in press</i>
South Africa								
Lake Mchizane, Zimbabwe	5.0 (ND-161)*	19 (2-42)*				1.0 (ND-12)*		Mhlanga and Madhwa, 1990
Lake Mchizane, Zimbabwe	4							Griechus <i>et al.</i> , 1978a
Lake Mchizane, Zimbabwe	2							Griechus <i>et al.</i> , 1977
Harlemersfont Dam, RSA	<1							Griechus <i>et al.</i> , 1977
COASTAL WATERS								
North Africa - Egypt				0.05				Tarek, 1991
Abou Khar Bay	0.09							

*1, ng/g wet weight
ND = Not detected

Table III (cont.)
Concentration of chlorinated hydrocarbons in African inland and coastal water sediments (ng/g dry weight)

Location/water type	P,p'-DDE	P,p'-DDD	P,p'-DDT	Total DDT	PCB	Reference
INLAND WATERS						
North Africa - Egypt						
Lake Maryout	583	58.2	202	877	71.2	Saad et al., 1985
Lake Mariut	8.5	6.6	14.7	29.8	17.8	Saad et al., 1985
Lake Mariut	768		86.3			Abu Elmagd et al., 1979
Lake Mariut	1872.8		270.5			Saad, 1981
Norika Hydrodrome	12.4	1.8	24.8	54.1	21.4	Saad et al., 1985
Norika Hydrodrome	840.5					Abu Elmagd et al., 1979
Norika Hydrodrome	458.0		81			Saad, 1981
East Africa						
Lake Nakuru, Kenya	10	10	<10		<20	Grichas et al., 1978a
Lake Kyoga ya Mungu, Tanzania	1 (ND-1)	1 (ND-3)	3 (2-7)			Parsons et al., 1988
West and Central Africa						
River Dnyana, Sudan, Nigeria	13 (ND-32)	ND	0.1 (ND-5.3)		ND	Sunder, 1990
River Dnyana, Sudan, Nigeria	7 (ND-14)	ND	1 (ND-2)		ND	Sunder, 1990
River Dnyana, Nigeria	9 (ND-50)	ND	ND		4 (ND-14)	Sunder, 1990
Lake Lagos, Nigeria	263 (11-555)	ND	88 (ND-438)			Ojo, 1991
Elbe Lagoon, Côte d'Ivoire	7.4 (0.1-143)	28.1 (0.2-803)	15.7 (0.2-354)	17.1 (1.1-997)	48.7 (2-213)	Marchand and Maron, 1985
Elbe Lagoon, Côte d'Ivoire				48.2 (2.5-242.8)	355.5 (8.5-1014)	Kaba, in press
Southern Africa						
Lake Malheur, Zimbabwe				76 (32-148)*		Mhanga and Madzima, 1990
Lake Kariba, Zimbabwe				(40-740)		Matheson, 1983
Lake Kariba, Zimbabwe	15	40	2	57	120	Grichas et al., 1978a
Harboursport Dam, RSA	10	18	13	45	320	Grichas et al., 1977
Vaal Dam, RSA	5	2	8	13	70	Grichas et al., 1977
COASTAL WATERS						
North Africa - Egypt						
Abu Kira Bay				1.73		Tayel, 1981

*1 ng/g wet weight
ND = Not detected

Table IV
Concentration of chlorinated hydrocarbon residue in fish from African inland waters (ng/g fresh weight)

Country/location	Dieldrin	αHCH	γHCH	βHCH (Lindane)	Heptachlor	Albin	Endosulfan	Reference
North Africa								
Lake Mariut, Egypt				34.98				Saad <i>et al.</i> , 1992
Lake Mariut, Egypt		2.03		90.08				Saad, 1991
East Africa - Kenya								
Lake Nakuru	7*							Grechus, 1979b
Lake Nakuru	1.5-2.4							Kieman <i>et al.</i> , 1972
Tana River (Masinga Dam)		14 (9-21)		91.4 (4-295)				Mugachiri <i>et al.</i> , 1992a
Tana River (Rohia Irrigation Scheme)							20 (ND-110)	Munga, 1999
Lake Victoria	10							Kieman and Penning, 1970
Lake Victoria	(7-70)	(1-40)		(1-7)		20		Milawa and Gies, 1990
Lake Victoria			0.93(0.11-3.08)*					Calanier <i>et al.</i> , 1992
East Africa - Uganda								
Lake	5 (2-27)							Srenstrup, 1974, 1979
East Africa - Tanzania								
Lake Nyungu ya Mungu	3*			1*				Pasewitz <i>et al.</i> , 1999
West and Central Africa - Nigeria								
Southwest Ogun and Oyo States			12.7 (8-120)		50 (1-3000)		173 (3-304)	Arakwa, 1994
Southwest (Ogun River and Awea River States)		1.9 (0.2-7.4)		4.4 (0.8-13)	0.3 (ND-1.0)	5.5 (ND-14.9)	14 (ND-89.6)	Fayomi, 1997
Budan		0.15 (0.04-0.24)		248 (0.2-598)	0.9 (0.1-1.3)	1.4 (0.1-3.9)	ND	Odehinde and Jensen, 1990
Oyo, Lagos and Cross River States	69 (ND-173)	1.9 (0.2-5.0)						Arakwa, 1994, Fayomi, 1997
South Africa								
Khwe River, Botswana	(0-3.9)		(10-148)				30 (ND-190)	Matheson <i>et al.</i> , 1992
Lake Malwane, Zimbabwe	1.3 (ND-24)	64.1 (ND-240)				ND		Mitanga and Madzore, 1990
Lake Malwane, Zimbabwe	10-40*							Grechus <i>et al.</i> , 1979a
Harlemersfont Dam, RSA	80*							Grechus <i>et al.</i> , 1977
Vaal Dam, RSA	27*							Grechus <i>et al.</i> , 1977

*1: Original data on dry weight basis, converted to fresh weight values by dividing by 3
ND = Not detected

Table IV (cont.)
Concentration of chlorinated hydrocarbon residue in fish from African inland waters (ng/g fresh weight)

Country/Location	$\mu\text{g/g DDE}$	$\mu\text{g/g DDD}$	$\mu\text{g/g DDT}$	Total DDT	PCB	Reference
North Africa						
Qayna Research Farm, Sudan	670 (20-3600)	780 (50-4200)	1 470 (180-8 200)	2850 (270-16000)		El Zergani, 1976
Lake Nubia, Sudan	48 (1-153)		8 (5-14)	58 (6-184)		El Zergani et al., 1979
Lake Mariut, Egypt	38.88		17.36	60.76		Saad et al., 1982
Lake Mariut, Egypt	10.1		31.8	84.5		Saad, 1981
East Africa - Kenya						
Lake Nakuru	7*	3*	<3*	<13*	<150*	Geshchko, 1978b
Lake Nakuru	1.3-2	<7	<2	<11		Koeman et al., 1972
Lake Nakuru	25*					Lincer et al., 1981
Lake Nakuru	46					Brown, 1971
Lake Naivasha	2.8*					Lincer et al., 1981
Lake Naivasha	14.48*					Lincer et al., 1981
Tana River (Maraungu Dam)	121.4 (15-220)		171.8 (52-1 125)	90.4 (85-1185)		Mugisha et al., 1992a
Tana River (Hells Inlet/Schwarze)	247 (ND-1300)	8 (ND-40)	3 (ND-10)	254 (ND-1350)		Mugisha et al., 1992b
Atto River	10			36		Koeman and Pennings, 1970
Lake Victoria	13-360	110-220	20	180-460		Mama and Giesu, 1980
Lake Victoria	4.4 (0-43.10-91*)	7.8 (2.67-16.03)*	3.0 (0.17-7.4)*	15.2 (8-28)*	90.4 (20-332)*	Colaneri et al., 1992
East Africa - Tanzania						
Lake Nyumba ya Mungu	9*	2*		8*		Fisahl, 1981
Lake Tanganyika			48 (5-125)*	165 (50-330)*		Pasovic et al., 1988
West and Central Africa - Nigeria						Desbrière et al., 1976
Southwest (Ogem and Oyo States)	3.4 (2-20)	7.8 (2-60)	2.8 (3-18)	20.6 (3-161)	28.7 (8-120)	Amadike, 1984
Southwest (Cross River and Akwa Ibom States)	1.8 (ND-4.2)	0.7 (ND-8)		2.5	3.8 (0.7-14)	Fayomi, 1987
South Africa						
Illovo		3 (0-2-8-6)	7 (ND-23)	15 (0-5-38)		Gidycz and Jensen, 1980
South Africa - Botswana						
Kruger River, Botswana						Muthusami et al., 1982
Lake Molewane, Zimbabwe				66.6		Mitanga and Madziva, 1980
Lake Molewane, Zimbabwe	27.80*	33.80*	<3.47*	60-150*	400-770*	Geshchko et al., 1978a
Lake Kariba, Zimbabwe				170		Muthusami, 1983
Harbourport Dam, RSA	77*	100*	87*	244*	820*	Geshchko et al., 1977
Vaal Dam, RSA	160*	20*	180*	370*	600*	Geshchko et al., 1977

*1. Original data on dry weight basis, converted to fresh weight values by dividing by 3

ND = Not detected

Table V
Concentration of chlorinated hydrocarbon residue in fish from coastal and marine African waters (ng/g fresh weight)

Country/Location/Species	Dioxin	HCB	PCCH (Lindane)	Hepachlor	Aldrin	Endosulfan	Reference
West and Central Africa							
Fish							
Nigeria		0.82 (0.04-8.48)	0.83 (ND-5.30) 12.4 (2-55)	1.28 (ND-21.40)	2.85 (ND-54.60)	0.16 (ND-4.95)	Odeh and Banglase, 1990
Sierra Leone			0.10	0.02	<0.006		Peterson et al., 1989
Benin	0.28	<0.016	0.41 (<0.03-0.81)*	0.1 (<0.04-0.23)*	0.18 (0.03-0.31)*		Stoll and Kuhn, 1992
Côte d'Ivoire	0.46*		0.028	0.15			Kuhn, 1982
Gambia		0.58	1.60 (ND-7.31)		2.4 (ND-12.3)		Jallow, 1988
Cameroon							Mbome and Mbome, 1981
Shellfish							
Nigeria shrimp, crab, oyster, snail		0.22 (ND-0.80)	0.80 (ND-1.68)	1.35 (ND-4.16)	0.52 (ND-1.84)	2.41 (ND-21.0)	Odeh and Banglase, 1990
Côte d'Ivoire shrimp			0.31 (<0.03-0.73)*	0.37 (0.17-0.81)*	0.65 (0.17-1.31)*		Kuhn, 1982
Gambia shrimp		3.07	0.74	1.08			Jallow, 1988
Cameroon oyster		1.74	0.18		ND		Jallow, 1988
Cameroon shrimp			0.98 (0.28-1.76)				Mbome and Mbome, 1981
Cameroon oyster			1.44 (ND-5.31)				Mbome and Mbome, 1981
East and Central Africa							
Fish							
Nigeria	3.72 (0.13-14.30)						Odeh and Banglase, 1990
Sierra Leone	15 (2-36)	0.12 (ND-1.05)	11 (2-30)	4.37 (0.15-18.60)	46 (7-116)	40.8 (11.0-225)	Peterson et al., 1989
Benin	0.28	1.78	1.86	3.88		90 (2-825)	Stoll and Kuhn, 1992
Côte d'Ivoire				1.82 (0.13-4.3)*			Kuhn, 1982
Cameroon				83.5 (ND-383)		180 (ND-893)	Mbome and Mbome, 1981
Shellfish							
Nigeria shrimp, crab, oyster, snail				37.0 (4.73-153)		94.5 (37-387)	Odeh and Banglase, 1990
Côte d'Ivoire shrimp				1.0 (0.17-1.8)*			Kuhn, 1982
Cameroon shrimp				244 (78-540)		342 (ND-705)	Mbome and Mbome, 1981
Cameroon oyster				113 (ND-181)		208 (ND-710)	Mbome and Mbome, 1981

*1) Original data on dry weight basis, converted to fresh weight values by dividing by 3
ND = Not detected

Table VI
Mean concentration of chlorinated hydrogen residue in aquatic plants (ng/g dry weight)

Country Location/Species	Durbin	dDCH	HCB	pHCH (Lindene)	Heptachlor	Alrin	Endosulfan	Reference
INLAND WATERS								
East Africa								
Lake Uganda	90 115 3000 ¹							Sanyalaji, 1874, 1878
highland plants								
L. Nyumbika ya Mungu, Tanzania	27			4.5		Tenaxolins 2%		Pasavento et al., 1988
Phila. strubosus								
Southern Africa								
Herbertspont Dam, RSA	5D							Grechus et al., 1977
Algae	2D							Grechus et al., 1977
COASTAL WATERS								
Ogbe Lagoon, Badagry, Nigeria	4.3	0.45		48.8	5.2	ND	17	Ogimaelin, 1997
Water Hyacinth								
INLAND WATERS								
East Africa								
Lake Naivasha, Kenya								
Algae	7							Lincei et al., 1991
Highland plants	3D							Lincei et al., 1991
Ferns (Chelone aureoloides)	107							Lincei et al., 1991
Tall vegetation	31							Lincei et al., 1991
Lake Nakuru, Kenya								Lincei et al., 1991
Oxycobana phillipsii								Lincei et al., 1991
Lake Baringo, Kenya								Lincei et al., 1991
highland plants (plant parts with algae and Spongyral)	ND trace							Lincei et al., 1991
L. Nyumbika ya Mungu, Tanzania	15		ND	19				Pasavento et al., 1988
Phila. strubosus								
Southern Africa								
Herbertspont Dam, RSA	6D		200	280			2500	Grechus et al., 1977
Algae	2D		80	130			1300	Grechus et al., 1977
Water hyacinth								
COASTAL WATERS								
Ogbe Lagoon, Badagry, Nigeria	ND		ND	ND			2700	Dunstan, 1987
Water Hyacinth								

¹ Original data on fresh weight basis, converted to dry weight values by multiplying by 3

ND = Not detected

REFERENCES

- Abu-Elmeyer, M.M., M.A.H. Saad and A.H. El-Sebae, 1979. Water pollution with organochlorine pesticides in Egyptian lakes. In Environment protection from hazards of pesticides. Proceedings of an international Egyptian-German Seminar, March 24-29, 1979. Bad Godesberg, Germany, Deutscher Akademischer Austauschdienst, pp 94-108
- Adedayo, S.O., 1990. Characterisation of leachate from selected refuse dumps in Ibadan, Nigeria. M.Sc. Thesis, Department of Chemistry, University of Ibadan, Nigeria
- Adekambi, E.O., 1989. Petroleum hydrocarbons in coastal waters and sediments in Nigeria. PhD. Thesis, Department of Chemistry, University of Ibadan, Nigeria
- Adeniji, H.A. et al., 1991. A review of studies on the assessment of water quality in Nigerian inland waters. In Proceedings of the First national symposium on water quality monitoring and status in Nigeria, 6-18 October 1991, Kaduna, Nigeria. Lagos, Federal Environmental Protection Agency
- Adeyanju, B., 1979. Sewage disposal in Lagos stinks. Lagos, Daily Time, 6 October, p.7
- Agunloye, T.O., 1984. A survey of chlorinated hydrocarbons in rivers of southern Nigeria. MSc. Thesis. Department of Chemistry, University of Ibadan, Nigeria
- Ajayi, T.R., 1981. Statistical analysis of stream sediment data from the Ife-Ilesha area of southwestern Nigeria. J. Geochem. Explor., 15:539-48
- Ajayi, S.O. and O. Osibanjo, 1981. Pollution studies on Nigerian rivers. 2. Water quality of some Nigerian rivers. Environ. Pollut. (B), 2:87-95
- Akhabuhaya, J. and M. Lodenius, 1988. Metal pollution of river Msimbazi, Tanzania. Environ. Int., 14:511-4
- Akoto Bamford, S. et al., 1990. Environmental impact of the gold mining industry in Ghana. Biol. Trace Elem. Res., 26:279-85
- Alabaster, J.S., 1981. Review of the state of aquatic pollution of East African inland waters. CIFA Occas. Pap., (9):36p.
- Alabaster, J.S. and R. Lloyd, 1982. Water quality criteria for freshwater fish. 2nd edition. London, Butterworth, 361 p.
- Alala, L.N.N., 1981. Heavy metal concentrations in Kenyan lakes. MSc. Thesis, University of Nairobi, Kenya, 181 p.
- Alford-Stevens, A.L., 1986. Analyzing PCBs. Environ. Sci. Technol., 20(12):1194-9

References

- Alkbrant, F., 1979. Rural water quality programme in Tanzania. Final report. Ministry of Water Development, Energy and Minerals. Stockholm, Swedish International Development Authority, 328 p. (10 annexes)
- Amakwe, C., 1984. Organochlorine pesticide residues in Nigerian freshwater fish. BSc. Dissertation. Department of Chemistry, University of Ibadan, Nigeria
- Amasa, S.K., 1975. Arsenic pollution at Obuasi gold mine, town and surrounding countryside. Environ.Health Perspect., 12:131-5
- Amuzu, A.T., 1973. Some aspects of the limnology of Lake Barekese in the Ashanti region of Ghana. Technical report. Accra, Ghana Water and Sewerage Corporation
- Amuzu, A.T., 1975. Water-treatment practices of the Barekese water utility in Ghana. J.Am.Water Works Assoc., 67(6):322-3
- Angelidis, M. et al., 1981. Trace elements in sediments of Evoikos Gulf, Greece. Journ. Etud.Pollut., CIESM, 5:413-8
- APHA/AWWA/WPCF, 1985. Standard methods for the examination of water and wastewater. 16th ed. Washington, American Public Health Association, 1268 p.
- Arebun, O.H., 1990. Characterisation of priority pollutants in Aperin and Ring Road refuse dumps in Ibadan, Nigeria. MSc. Thesis. Department of Chemistry, University of Ibadan, Nigeria.
- Armour, J.A. and J.A. Burke, 1970. Method of separating PCB from DDT and its analogs. J.Assoc.Off.Anal.Chem., 53:761-8
- Autrique, A., 1977. La lutte contre les déprédateurs du cotonier au Burundi. Bujumbura, Institut des Sciences Agronomiques du Burundi, Département Défense des Végétaux, 9 p.
- Awanda, C.O.A., 1987. Effects of industrial effluents on the biota of River Kaduna. Ph.D. Thesis, Department of Biological Sciences. Zaria, Nigeria, Ahmadu Bello University, 286 p.
- Ba, D., 1988. Analyse des contaminants chez les organismes marins d'importance commerciale dans les eaux côtières du Sénégal. Report presented to Second Workshop of participants in the Joint FAO/IOC/WHO/AEA/UNEP Project on pollution in the marine environment of the west and central African region (WACAF/2-First Phase), Accra, Ghana, 13-17 June 1988. Paris, IOC of Unesco, 28 p.
- Ba, D. et al., 1985. Recherche et dosage des traces des métaux lourds dans des organismes marins au Sénégal. IOC Workshop Rep., (41)Annex V.3:8p.

References

- Baldry, D., D. Calamari and L. Yaméogo, 1994. Environmental impact assessment of settlement and development in the Onchocerciasis Control Programme area in West Africa. Pilot study in the upper Léraba basin, Burkina Faso, Côte d'Ivoire and Mali. World Bank Tech.Pap., (in press)
- Balk, I.R. and J.H. Koeman, 1984. Future hazards from pesticide use. IUCN Comm.Ecol.Pap., (6):100p.
- Barel, C.D.N. et al., 1985. Destruction of fisheries in Africa's lakes. Science (Wash.), (315):16-20
- Basak, S.C., D.P. Gieschen and V.R. Magnuson, 1984. A quantitative correlation of the LC50 values of esters in *Pimephales promelas* using physico chemical and topological parameters. Environ.Toxicol.Chem., 3:191-9
- Beecroft, B.A. et al., 1987. An overview of the environmental problem in Kaduna. A report by the Kaduna Pollution Study Group. Chemical Engineering Department, Zaria, Nigeria, Ahmadu Bello University.
- Belay, A. and R.B. Wood, 1984. Primary productivity of five Ethiopian Rift Valley lakes. Verh.Int.Ver. Theor.Angew.Limnol., 22:1187-92
- Bellinger, E.G. and B.R. Benham, 1987. The levels of metals in dock-yard sediments with particular reference to the contributions from ship-bottom points. Environ.Pollut., 15:71-81
- Bernhard, M., 1988. Mercury in the Mediterranean. UNEP Reg.Seas Rep.Stud., (89): 141p.
- Bernhard, M. and A. Renzoni, 1977. Mercury concentration in Mediterranean marine organisms and their environment: natural or anthropogenic origin. Thalassia Jugosl., 13:265-300
- Biney, C., 1982. Preliminary survey on the state of pollution of the coastal environment of Ghana. Oceanol.Acta, 4 Suppl. (Vol.spec.):39-43
- Biney, C.A., 1985. Trace metal levels in fish from Ghana. IOC Workshop Rep., (41) Annex V.1:9p.
- Biney, C.A., 1991. The distribution of trace metals in the Kpong Headpond and Lower Volta River, Ghana. In Perspectives in aquatic ecotoxicology, edited by N.K. Shastree. Delhi, India, Narendra Publ. House
- Biney, C.A., 1991a. A method for characterizing natural and waste waters using plant seeds. Environ.Monit.Assess., (18):123-8
- Biney, C.A. and E. Ameyibor, 1989. Trace metal concentrations in the pink shrimp (*Penaeus notialis*) from the coast of Ghana. WACAF-2 Newsl.FAO Rome, 5(1):7-9

References

- Biney, C.A. and C.A. Beeko, 1991. Trace metal concentrations in fish and sediment from the Wiwi, a small urban river in Kumasi, Ghana. Trop.Ecol., 32(2):197-206
- Biney, C. *et al.*, 1987. Scientific bases for pollution control in African inland waters. Chem.Ecol., 3:49-74 and FAO Fish.Rep., (369):9-23
- Biney, C. *et al.*, 1994. Review of heavy metals in the African aquatic environment. Ecotoxicol.Environ.Saf., 28:134-59 and FAO Fish.Rep., (471):7-43 (1992)
- Bradley, R.W. and J.R. Morris, 1986. Heavy metals in fish from a series of metal contaminated lakes near Sudbury, Ontario. Water Air Soil Pollut., (27):341-54
- Brodie, J.E. *et al.*, 1990. State of the marine environment in the South Pacific Region. UNEP Reg.Seas.Rep.Stud., (127):59p.
- Bro-Rasmussen, F. and K. Christiansen, 1984. Hazard assessment. A summary of integrated evaluation of exposure and potential effects from toxic environmental chemicals. Ecol. Modelling, 22:67-84.
- Brown, L., 1971. All well so far at Lake Naivasha. Africana, 4(8):11-2
- Bryceson, I. *et al.*, 1990. State of the marine environment in the Eastern African Region. UNEP Reg.Seas.Rep.Stud., (113):46p.
- Bugenyi, F.W.B., 1979. Copper ion distribution in the surface waters of Lakes George and Idi Amin. Hydrobiologia, 64:9-15
- Bugenyi, F.W.B., 1982. Copper pollution studies in Lakes George and Edward, Uganda: the distribution of Cu, Cd, and Fe in the water and sediments. Environ.Pollut.(B), 3:129-38
- Bugenyi, F.W.B., 1984. Potential aquatic environmental hazards of agro-based chemicals and practices in a developing country, Uganda. Proc.Int.Conf.Environ.Haz. Agrochem., (1):461-73
- Bugenyi, F.W.B. and J.S. Balirwa, 1989. Human intervention in natural process of the Lake Victoria ecosystem. The problem. In Conservation and management of lakes, edited by J.Salanki and S. Herodek. Biol.Hung., 38:311-40
- Burgis, M.J., 1978. Case studies of lake ecosystems at different latitudes: the tropics. Verh.Int.Ver.Theor.Angew.Limnol., 20:1139-52
- Burgis, M.J. and J.J. Symoens, 1987. African wetlands and shallow water bodies/Zones humides et lacs peu profonds d'Afrique. Directory/Repertoire. Trav.Doc.Inst.Fr. Rech.Sci.Dev.Coop., (211):650p.
- Burns, L.A., M.D. Cline and R. Lassiter, 1981. Exposure analysis modelling system (EXAMS): user manual and system documentation. Athens, Georgia, U.S. EPA Environmental Research Laboratory, pag. var.

- Burton, J.D., 1976. Basic properties and processes in estuarine chemistry. *In* Estuarine chemistry, edited by J.D. Burton and P.S. Liss. London, Academic Press, pp 1-36
- Cairns, T. and E.G. Siegmund, 1981. PCBs - Regulatory history and analytical problems. *Anal.Chem.*, 11:1183A-93A
- Calamari, D., 1984. Studi di tossicologia. *In* Problemi di tossicologia generale, edited by N. Lo Prieno. Pisa, ETS, pp 31-50.
- Calamari, D., 1985. Review of the state of aquatic pollution of West and Central African inland waters. *CIFA Occas.Pap.*, (12):25p.
- Calamari, D. and G. Chiaudani, 1984. Problems and methods in defining water quality criteria of micropollutants in aquatic ecosystems. *In* Proceedings of the third conference of prevention of pollution by substances derived from wastes, Rome, 11-12 May 1981, edited by D. Calamari. Roma, Consiglio Nazionale delle Ricerche, pp 302-20.
- Calamari, D., M.O. Akech and P.B.O. Ochumba, 1994. Pollution of Winam Gulf, Lake Victoria, Kenya. A case study for preliminary hazard assessment. Paper presented at the CIFA Seminar on African Inland Fisheries, Aquaculture and the Environment, Harare, Zimbabwe, 5-7 Decambar 1994. Rome, FAO, CIFA/94/Sem.A-25, 23 p.
- Calamari, D., *et al.*, 1980. Biodegradation and toxicity of selected amines on aquatic organisms. *Chemosphere*, 9:753-62
- Calamari, D., *et al.*, 1983. Toxicity of selected chlorobenzenes to aquatic organisms. *Chemosphere*, 12:253-62
- Corbet, P.S., 1958. Some effects of DDT on the fauna of Victoria Nile. *Rev.Zool.Bot. Afr.*, 57:73-95
- Croll, B.T., 1969. Organochlorine insecticides in water. Part 1. *Water Treat.Exam.*, 18:255-74
- Croll, B.T., 1991. Pesticides in surface waters and groundwaters. *J.Int.Water Environ. Manage.*, 5:389-95
- Davies, B. and F. Gasse, 1988. African wetlands and shallow water bodies/Zones humides et lacs peu profonds d'Afrique. Bibliography/Bibliographie. *Trav.Doc.Inst. Fr.Rech.Sci.Dev.Coop.*, (211):502p.
- Deelstra, H., J.L. Power and C.T. Kenner, 1976. Chlorinated hydrocarbon residues in the fish of Lake Tanganyika. *Bull.Environ.Contam.Toxicol.*, 15(6):689-98
- Dejoux, C., 1988. La pollution des eaux continentales africaines. Expérience acquise, situation actuelle et perspectives. *Trav.Doc.Inst.Fr.Rech.Sci.Dév.Coop.*, (213): 513p.

References

- Dejoux, C., H. Deelstra and R. Wilkinson, 1981. Pollution. In The ecology and utilization of African inland waters, edited by J. Symoens, M. Burgis and J. Gaudet. UNEP Rep.Proc.Ser., (1):149-61
- Edwards, C.A., 1977. Nature and origins of pollution by pesticides. In Pesticides in aquatic environments, edited by M.A.Q. Khan. New York, Plenum Press, pp 11-38
- EEC, 1978. Council directive of 18 July 1978 on the quality of fresh water needing protection or improvement in order to support fish life. Off.J.Europ.Commun., (L222):1.
- EEC, 1979. Council directive 79/831. Off.J.Europ.Commun., (L259):10p.
- Eichelberger, J. W. and J.J. Lichtenberg, 1971. Persistence of pesticides in river water. Environ.Sci.Technol., 5(6):541-4
- EIFAC Working Party on toxicity testing procedures, 1983. Revised report on fish toxicity testing procedures. EIFAC Tech.Pap., (24)Rev.1:37p.
- EIFAC Working Party on Water Quality Criteria for European Freshwater Fish, 1980. Report on combined effects on freshwater fish and other aquatic life of mixtures of toxicants in water. EIFAC Tech.Pap., (37):49p.
- EIFAC Working Party on Water Quality Criteria for European Freshwater Fish, 1987), Report on combined effects on freshwater fish and other aquatic life of mixtures of toxicants in water. EIFAC Tech.Pap., (37) Rev.1:75p.
- Eisenreich, S.J., G.J. Hollad and T.C. Johnson, 1979. Accumulation of polychlorinated biphenyls (PCBs) in surficial Lake Superior sediments. Atmospheric deposition. Environ.Sci.Technol., 13:569-73
- Eisler, R. et al., 1977. Survey of metals in sediments near Quonset Point, Rhode Island. Mar.Pollut.Bull., 8(11):260-4
- Ekundayo, J.A., 1977. Environmental consequences of the pollution of the Lagos Lagoon. Bull.Sci.Assoc. Nigeria, 3(2):290-9
- El-Dib, M.A. and M.I.Badway, 1985. Organochlorine insecticides and PCBs in water, sediment and fish from Mediterranean Sea. Bull.Environ.Contamin.Toxicol., 34: 215-27
- El Nabawi, A., B. Heinzow and H. Kruse, 1987. As, Cd, Cu, Pb, Hg and Zn in fish from the Alexandria Region, Egypt. Bull.Environ.Contam.Toxicol., 39:889-97
- El Rafei, S., S.I. El Shawarby and F.A. Fahim, 1987. Heavy metals in waste water to the Nile. Desalination, 67:355-62
- El-Rayis, A.O. and M.A.H. Saad, 1985. Concentration of Cu, Cd, Zn, Fe and Mn in the Nile river water and its contribution to the Mediterranean. Journ.Etud.Pollut.CIESM, 7:45-52

- El-Rayis, O. and M.A. Saad, 1986. Origins of trace elements in a main land-based source on the North African coast, west of the Nile delta. Rapp.P.-V. Réunion.CIESM., 30(2):33
- El-Rayis, O. and M. Saad, 1986a. Heavy metals in suspended matters and sediments from a confined lagoon on the North African coast, Egypt. Rapp.P.-V. Réunion. CIESM., 30(2):50
- El-Rayis, A.O. and M.A.H. Saad, 1990. Heavy metal pollution in Lagoon Mariut on the southern coast of the Eastern Mediterranean Sea. King Abdul Aziz Univ.Mar.Sci., 1:17-26
- El-Rayis, O., M. Saad and F. El-Nady, 1986. Accumulating mechanisms of metals in surface sediments of a coastal bay on the North African coasts. Rapp.P.-V. Réunion. CIESM., 30(2):65
- El-Sebae, A.H. and M.A. Abu-Elamayem, 1979. A survey to determine potential pollution of the Mediterranean by pesticides from the Egyptian region. Journ.Etude.Pollut., CIESM., (4):149-53
- El-Zorgani, G.A., 1976. Residues of organochlorine insecticides in some fishes and birds in the Gezira of Sudan. Pestic.Sci., 7:150-2
- Elzorgani, G.A., A.M. Abdulle and M.E.T. Ali, 1979. Residues of organochlorine insecticides in fishes in Lake Nubia. Bull.Environ.Contam.Toxicol., 22:44-8
- Environmental Management Associates, 1989. Environmental Study of Accra Metropolitan Area. Accra, UNDP, 236 p.
- Ernst, W.E. et al., 1983. Monitoring of organochlorine compounds in some marine organisms from Alexandria region. In Proceedings of the First International conference on environmental hazards of agrochemicals, Alexandria, 8-12 November 1983, edited by A.K.H. El-Sebae et al., Alexandria University, pp 95-108
- Fahmy, M.A., 1981. Seasonal distribution of heavy metals in the Damietta branch of the Nile. MSc. Thesis, Faculty of Science, University of Alexandria, Egypt
- Fayed, S.E. and H.I. Abd El-Shafy, 1985. Accumulation of Cu, Zn, Cd and Pb by aquatic macrophytes. Environ.Int., 11:77-87
- Fayomi, S.F., 1987. Determination of organochlorine pesticides and polychlorinated biphenyls (PCBs) in Nigerian fresh water fishes from Cross River State of Nigeria. BSc. Dissertation, Department of Chemistry, University of Ibadan, Nigeria.
- FAO, Plant Production and Protection Division, 1988. Report of the Twenty-Ninth Session of the FAO desert locust control committee, Rome, 13-17 June 1988. Meeting Report No. AGP/1988/M/2, 38 p.
- FAO, 1989. Food safety regulations applied to fish by major importing countries. FAO Fish.Circ., (825):107p.

References

- FAO, 1990. International code of conduct on the distribution and use of pesticides (Amended version), Rome, FAO, M/0610E:34p.
- Förstner, U. and G.T.W. Wittmann, 1981. Metal pollution in the aquatic environment. 2nd edition. Berlin, Springer, 486 p.
- Foxall, C., 1981. Levels of organochlorine biocide residues in fish from Lake Victoria. Some preliminary findings. In Proceedings of the Workshop of the Kenya Marine and Fisheries Research Institute on aquatic resources of Kenya. Mombasa, KMFRI, pp 256-63
- Frank, R. *et al.*, 1977. Organochlorine insecticides and PCBs in sediments of Lake St Clair (1970 and 1974) and Lake Erie (1971). Sci.Total Environ., 8:205-27
- Gayner, H., D. Freitag and F. Forte, 1984. Polychlorinated biphenyls (PCBs) in the marine environment, particularly in the Mediterranean. Ecotoxicol.Environ.Saf., 8:129-51
- Gerike, P. and W.K. Fisher, 1979. A correlation study of biodegradability determinations with various chemicals in various tests. 1. Ecotoxicol.Environ.Saf., 3:159-73
- Gerike, P. and W.K. Fisher, 1981. A correlation study of biodegradability determinations with various chemicals in various tests. 2. Ecotoxicol.Environ.Saf., 5:45-55
- GESAMP (IMO/FAO/UNESCO/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Pollution), 1982. The Health of the Oceans. Rep. Stud.GESAMP, (15):108p. and UNEP Reg.Seas Rep.Stud., (16):108p.
- GESAMP (IMO/FAO/UNESCO/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Pollution), 1985. Review of potentially harmful substances - Cadmium, lead and tin. Rep.Stud.GESAMP, (22):116p. and UNEP Reg.Seas Rep.Stud., (56):85p.
- GESAMP (IMO/FAO/Unesco/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Pollution), 1986. Environmental capacity. An approach to marine pollution prevention. Rep.Stud.GESAMP, (30):49p.
- GESAMP (IMO/FAO/UNESCO/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Pollution), 1988. Review of potentially harmful substances - Arsenic, mercury and selenium. Rep.Stud.GESAMP, (28):172p. and UNEP Reg.Seas Rep.Stud., (92):172p.
- GESAMP (IMO/FAO/Unesco/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Pollution), 1989. The atmospheric input of trace species to the world oceans. Rep.Stud.GESAMP, (38):111p.
- GESAMP (IMO/FAO/Unesco/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Pollution), 1991. Review of potentially harmful substances: carcinogens. Rep.Stud.GESAMP, (46):56p.
- Goldberg, E.D., 1976. The health of the oceans. Paris, Unesco, 172 p.

- Gomez, E.D. *et al.*, 1990. State of the marine environment in the East Asian Seas Region. UNEP Reg.Seas Rep.Stud., (126):63p.
- Gossett, R.W., D.A. Brown and D.R. Young, 1983. Predicting the bioaccumulation of organic compounds in marine organisms using octanol/water partition coefficients. Mar.Pollut.Bull., 14:387-92
- Gras, G. and J. Mondain, 1978. Teneur en mercure de quelques espèce de poisson pêchés sur les côtes du Sénégal. Rev.Int.Océanogr.Méd., 51-52:83-7
- Greichus, Y.A. *et al.*, 1977. Insecticides, polychlorinated biphenyls and metals in African lake ecosystems. 1. Hartbeespoort Dam, Transvaal and Voëlvele Dam, Cape Province, Republic of South Africa. Arch.Environ.Contam.Toxicol., 6:371-83
- Greichus, Y.A. *et al.*, 1978a. Insecticides, polychlorinated biphenyls and metals in African lake ecosystems. 2. Lake Mcllwaine, Rhodesia. Bull.Environ.Contam.Toxicol., 19: 444-53
- Greichus, Y.A. *et al.*, 1978b. Insecticides, polychlorinated biphenyls and metals in African lake ecosystems. 3. Lake Nakuru, Kenya. Bull.Environ.Contam.Toxicol., 19:454-61
- Haahiti, H. and M. Perttälä, 1988. Levels and trends of organochlorines in cod and herring in the northern Baltic. Mar.Pollut.Bull., 19:29-32
- Hansch, C., 1969. A quantitative approach to biochemical structure-activity relationships. Acc.Chem.Res., 2:232-9
- Hansch, C., 1973. Quantitative approaches to pharmacological structure-activity relationships. In Structure-activity relationships, edited by C. J. Cavallito. Oxford, Pergamon Press, Vol.1:75-165
- Hansen, L.G., 1987. Environmental toxicology of polychlorinated biphenyls. In Polychlorinated biphenyls (PCBs): mammalian and environmental toxicology, edited by S. Safe. Springer, Berlin, pp 15-48
- Haque, R. (ed.), 1980. Dynamics, exposure and hazard assessment of toxic chemicals. Ann Arbor, Michigan, Ann Arbor Science Publishers, 496 p.
- Haque, R. and V.H. Freed, 1975. Environmental dynamics of pesticides. New York, Plenum Press, 387 p.
- Harper, D., 1984. Recent changes in the ecology of Lake Naivasha, Kenya. Verh.Int.Ver.Theor.Angew.Limnol., 22:1193-7
- Harris, H. J. *et al.*, 1990. Ecotoxicology and ecosystem integrity: the Great Lakes examined. Environ.Sci.Technol., 24(5):598-632
- Hellawell, J.M., 1986. Biological indicators of freshwater pollution and environmental management. London, Elsevier, 546p.

References

- Harmans, J., P. Leeuwangh and A. Musch, 1984. Quantitative structure-activity and mixture toxicity studies of chloro- and alkyl-anilinas at an acute lethal toxicity level to the guppy (*Poecilia reticulata*). Ecotoxicol. Environ. Saf., 8:388-94
- Heydorn, A.E.F., 1970. The mounting threat to our estuaries. Afr. Wildl., 24:193-200
- Holdgate, M.W., 1979. A perspective of environmental pollution. Cambridge, Cambridge University Press, 278 p.
- Howalls G. (Ed.), 1994. Water quality for freshwater fish: Further advisory criteria. Reading, U.K., Gordon and Breach, 222 p.
- Hushon, J., 1982. Survey of scoring systems for hazard assessment. In Chemicals in the environment. Symposium Proceedings, edited by K. Christiansen, B. Koch and F. Bro-Resmussen. Lyngby, Copenhagen, Technical University of Denmark, pp 435-50.
- Hutchinson, T.C. and K.M. Meema, 1987. Lead, mercury and arsenic in the environment. SCOPE 31. Chichester, U.K., John Wiley and Sons, 360p.
- Hutzinger, O., 1980. The handbook of environmental chemistry. Vol. 2. Part A. Reactions and processes. Berlin, Springer Verlag, 307 p.
- Hutzinger, O., 1982. The handbook of environmental chemistry. Vol. 2. Part B. Reactions and processes. Berlin, Springer Verlag, 205 p.
- Hynes, H.B.N. and T.R. Williams, 1962. The effects of DDT on the fauna of a Central African stream. Ann. Trop. Med. Parasit., 55:192-6
- Institute of Aquatic Biology, 1990. Summary of trace metal analyses. WACAF/2 Phase 1 (1985-89). Accra, Institute of Aquatic Biology, 19p.
- IOC-Unesco, 1985. Second Workshop of participants in the Joint FAO/IOC/WHO/IAEA/UNEP Project on pollution in the marine environment of the West and Central African region (WACAF/2-First Phase), Accra, Ghana, 13-17 June 1988. IOC Workshop Rep., (62):pag. var.
- Jallow, S.B.O., 1988. Monitoring of organochlorine pesticides in the Gambia. Report presented to Second Workshop of participants in the Joint FAO/IOC/WHO/IAEA/UNEP Project on pollution in the marine environment of the West and Central African region (WACAF/2-First Phase), Accra, Ghana, 13-17 June 1988. Paris, IOC of Unesco
- Jensen, S., L. Renberg and L. Reutergårdh, 1977. Residue analysis of sediment and sewage sludge for organochlorines in the presence of elemental sulfur. Anal. Chem., 49(2):316-8
- Jensen, S. et al., 1972. DDT and PCB in herring and cod from the Baltic, the Kattégat and Skagerrak. Ambio, 1:81-4

- Jernelöv, A., 1975. Heavy metals in the marine environment. In Discharges of sewage from sea outfalls, edited by A.L.H. Gameson. Oxford, Pergamon, pp 115-30
- Kaba, N., 1992. Résidus d'organochlorés dans les milieux lagunaire et marin. Communication à la Journée AISA (Association Ivoirienne des Sciences Agronomique) Abidjan, mai 1992. Abidjan, Côte d'Ivoire, Centre de recherches océanologiques
- Kaba, N., in press. Résidus organochlorés dans les sédiments de la lagune Ebrié autour d'Abidjan (Côte d'Ivoire). J.Ivoir.Océanol.Limnol.
- Kahanovitch, Y. and N. Lahav, 1974. Occurrence of pesticides in selected water resources in Israel. Environ.Sci.Technol., 8:762-5
- Kakulu, S.E. and O. Osibanjo, 1986. A baseline study of mercury in fish and sediments in the Niger delta area of Nigeria. Environ.Pollut.(B), 11:315-22
- Kakulu, S.E. and O. Osibanjo, 1988. Trace heavy metal pollutional studies in sediments of the Niger delta area of Nigeria. J.Chem.Soc.Nigeria, 13:9-15
- Kakulu, S.E. and O. Osibanjo, 1992. Pollution studies of Nigerian rivers: Trace metal levels of surface waters in the Niger Delta area. Int.J.Environ.Stud., 41:287-92
- Kakulu, S.E., O. Osibanjo and S.O. Ajayi, 1987. Comparison of digestion methods for trace metal determination in fish. Intern.J.Environ.Anal.Chem., 30:209-17
- Kakulu, S.E., O. Osibanjo and S.O. Ajayi, 1987a. Trace metal content of fish and shellfishes of the Niger delta area of Nigeria. Environ.Int., 13:247-51
- Kallqvist, T. and B.S. Meadows, 1977. Pesticide levels in Kenyan rural environment. Afr.Environ., 2(4)/3(1):163-70
- Kallqvist, T. and B.S. Meadows, 1978. The toxic effect of copper on algae and rotifers from a soda lake (Lake Nakuru, East Africa). Water Res., 12:771-5
- Kanja, L.W., 1988. Organochlorine pesticides in Kenyan mothers milk. PhD. Thesis, University of Nairobi, Kenya
- Kaoma, C. and L.F. Salter, 1979. Environmental pollution in Zambia. In Proceedings of the National Seminar on Environment and Development, Lusaka, edited by D.S. Johnson and W. Roder. Occas.Stud.Zambia Geogr.Assoc., (10):181-216
- Karickhoff, S.W. D.S. Brown, and T.A. Scott, 1979. Sorption of hydrophobic pollutants on natural sediments. Water Res., 13:241-8
- Keith, L.H., 1976. Identification and analysis of organic pollutants in water. Ann Arbor, Mich., Ann Arbor Science Publishers, 718 p.
- Keith, L.H. and W.A. Telliard, 1979. Priority pollutants. 1. A perspective view. Envir.Sci.Technol., 13:416-23

References

- Kenaga, E.E. and C.A.I. Goring, 1980. Relationship between water solubility, soil sorption, octanol-water partitioning and concentration of chemicals in biota. *In* Aquatic Toxicology. Proceedings of the third annual symposium on aquatic toxicology, edited by J.G. Eaton, P.R. Parrish and A.C. Hendricks. ASTM Spec. Tech. Publ., (707):78-115
- Khan, M.A.Q., 1977. Pesticides in aquatic environments. New York, Plenum Press, 257 p.
- Kimerle, R.A., 1986. Has the water quality criteria concept outlived its usefulness? Environ.Toxicol.Chem., 5:113-5
- Koeman, J.H. and J.H. Pennings, 1970. An orientational survey on the side-effects and environmental distribution of insecticides used in tsetse control in Africa. Bull. Environ.Contam.Toxicol., 5:164-70
- Koeman, J.H. *et al.*, 1972. A preliminary survey of the possible contamination of Lake Nakuru in Kenya with some metals and chlorinated hydrocarbon pesticides. J.Appl.Ecol., 9:411-6
- Koeman, J.H. *et al.*, 1978. Three years' observation on side effects of helicopter applications of insecticides used to exterminate *Glossina* species in Nigeria. Environ.Pollut., 15:31-59
- Konemann, H., 1981. Quantitative structure-activity relationships in fish toxicity studies. 1. Relationship for 50 industrial pollutants. Toxicology, 19:209-21
- Konemann, H. and Calamari, D., 1983. Quantitative structure-activity relationship in aquatic toxicology. Working paper for 'Chemicals on which data are currently inadequate: selection criteria for health and environmental purposes'. OECD Existing Chemicals Programme. Paris, Organisation for Economic Co-operation and Development (mimeo)
- Kouadio, I. and J.H. Trefry, 1987. Sediment trace metals contamination in Ivory Coast, West Africa. Water Air Soil Pollut., 32:145-54
- Kurland, L.T., S.W. Faro and H. Siedler, 1960. Minamata disease: the outbreak of a neurological disorder in Minamata, Japan, and its relation to ingestion of sea food containing mercury compounds. World Neurol., 1:370-95
- Leonzi, C. *et al.*, 1981. Heavy metals in organisms from the North Tyrrhenian Sea. Sci. Total Environ., 20:131-46
- Lévesque, C., 1989. The use of insecticides in the Onchocerciasis Control Programme and aquatic monitoring in West Africa. *In* Ecotoxicology and climate, with special reference to hot and cold climates, edited by P. Bourdeau *et al.*, SCOPE 38, IPCS Joint Symposia 9. Chichester, U.K., John Wiley and Sons, pp 317-35
- Lévesque, C. *et al.*, 1989. Onchocerciasis Control Programme in West Africa. Ten years monitoring of fish populations. Chemosphere, 17:421-40

- Lewin, R., 1976. Chemical threat to Lake Nakuru. New Scientist, 71(1019):638-9
- Lincer, J.L. et al., 1981. Organochlorine residues in Kenya's Rift Valley lakes. J.Appl. Ecol., 18:157-71
- Lindén, O. et al., 1990. State of the marine environment in the ROPME Sea Area. UNEP Reg.Seas.Rep.Stud., (112)Rev.1:34p.
- Lloyd, R. end D. Calamari, 1987. Water quality criteria for European freshwater fish: the role of EIFAC (FAO). Water Anal.Bull., 12:100-3
- Mackay, D.N., 1982. Correction of bioconcentration factors. Environ.Sci.Technol., 16:274-8
- Mackay, D. and S. Paterson, 1981. Calculating fugacity. Environ.Sci.Technol., 15: 1006-14
- Mackay, D., D. Joy and S. Paterson, 1983. A quantitative water, air, sediment interaction (QWASI) fugacity model for describing the fate of chemicals in lakes. Chemosphere, 12:981-97
- Mackay, D., D. Joy and S. Paterson, 1983a. A quantitative water, air, sediment interaction (QWASI) fugacity model for describing the fate of chemicals in rivers. Chemosphere, 12:1193-208
- Macklad, F. et al., 1984a. Monitoring of chlorinated pesticides in some fish species from Edku Lake and Abu Kir Bay. Bull.High Inst.Publ.Health, Alexandria, 14:145-57
- Macklad, F. et al., 1984b. Monitoring of chlorinated pesticides in fish samples from Leke Mariut end Alexandria hydrodrome. Bull.High Inst.Publ.Health, Alexandria, 14: 161-73
- Magasa, J.H., 1978. Possible sources of aquatic pollution and their control in Malawi. Paper presented at the Sixth FAO/SIDA Workshop on equatic pollution in relation to protection of living resources, Nairobi end Mombesa, Kenya, 12 June - 22 July 1978. Rome, FAO, FIR/TPLR/78/Inf.25:2p.
- Marchand, M. and J.L. Martin, 1985. Détermination de la pollution chimique (hydrocarbures, organochlorés, métaux) dans la lagune d'Abidjan (Côte d'Ivoire) par l'étude des sédiments. Océanogr.Trop., 20(1):25-39
- Marchetti, R. et al., 1978. Elementi e criteri per la definizione del livello di accettabilita delle acque di scarico. Quad.Ist.Ric.Acque, (24):255p.
- Marshall, B.E., 1985. Limnology and fisheries management in Zimbabwe. Verh.Int.Ver. Theor.Angew.Limnol., 22:2671-5
- Martin, J.-M. and M. Whitfield, 1983. The significance of river input of chemical elements to the ocean. In Trace Metals in Sea Water, edited by C.S. Wong et E. Boyle. New York, Plenum Press, pp 265-96

References

- Martins, M.A., 1978. A study of the industrial effluents and waste disposal habits of some industries in the Iganmu end Apepa Industrial Estates of Lagos. MSc. Thesis, Department of Chemistry, University of Ibaden, Nigeria
- Mason, C.F., 1987. A survey of mercury and cadmium in muscle of British freshwater fish. Chemosphere, (16):901-6
- Matthews, A.D., 1981. Mercury in fish of the Republic of Seychelles and hair and blood mercury levels of part of the population exposed to methyl mercury through fish consumption. Fish.Bull.,Fish.Div.Seychelles, (9):62p.
- Metthiessen, P., 1983. Environmental contamination with DDT in Zimbabwe and its likely impact on wildlife. In Proceedings of The international conference on environmental hazards of agrochemicals in developing countries, Alexandria, Egypt, 8-12 November 1983, Vol 1:204-13. Alexandria, Egypt, Unesco and UNEP.
- Metthiessen P. and R.J. Roberts, 1982. Histopathological changes in the liver and brain of fish exposed to endosulfan insecticides during tsetse fly control operations in Botswana. J.Fish.Dis., 5:153-9
- Matthiessen, P. *et al.*, 1982. Accumulation of endosulfan residues in fish and their predators after aerial spraying for the control of tsetse fly in Botswana. Pest.Sci., 13:39-48
- Mbi, C.N. and L.I. Mbome, 1991. Pilot study on the levels of DDTs and PCBs in some marine fishery products from Cameroon. Rev.Sci.Tech.(Sci.Santé), in press
- Mbome, I.L., 1988. Heavy metals in marine organisms from Limbé and Douala. Report presented to Second Workshop of participants in the Joint FAO/IOC/WHO/IAEA/ UNEP Project on pollution in the marine environment of the west and central African region (WACAF-2-First Phase), Accre, Ghana, 13-17 June 1988. Paris, IOC of Unesco
- Mbome, L.I. and C.N. Mbi, 1991. Aldrin and lindane content of marine fishery products from Cameroon. Unpublished WACAF-2 project results. Yaounde, Cameroon, Centre de Nutrition
- Mbome, I.L. *et al.*, 1985. Preliminary survey on mercury and cadmium levels in some marine fishery products. Cameroon: Institut de recherches médicales et d'études des plantes médicinales, Yaoundé, Station de recherches halieutiques de Limbé. IOC Workshop Rep., (41)Annex V.2:7p.
- Mbote, W.M., 1979. Planning for national development. In Lectures presented at the Sixth FAO/SIDA Workshop on Aquatic pollution in relation to the protection of living resources. Scientific and administrative bases for management measures. Rome, FAO. TF-RAF 112(SWE)-Suppl.1:199-209
- McAuslan, J.P.W.B., 1980. Report on a National Environmental Protection Agency for Tanzania. Nairobi, UNEP, March 1980, 80 p.

- Meadows, B.S., 1978. Limnological investigation of lakes in Kenya, 1976-1977. Water Quality and Pollution Control Section, Resources Branch, Technical Report No. 6. Nairobi, Ministry of Water Development
- Meadows, B.S., 1980. The quality of water in Lake Victoria Basin and its protection. Semin.Ser.Lake Victoria Basin, Inst.Dev.Stud.Univ.Nairobi, (7)Rev.1:16 p.
- Merriman, J.C. and J.L. Metcalf, 1988. Pesticide distribution, Lower Ottawa River, 1986. Tech.Bull.Environ.Can., (160):10p.
- Metcalf, R.L., G.K. Sangha and I.P. Kapoor, 1971. Model ecosystem for the evaluation of pesticide degradability and ecological magnification. Environ.Sci.Technol., 5: 709-13.
- Métongo, B.S., 1985. Teneurs en métaux lourds dans les produits de pêche en Côte d'Ivoire. IOC Workshop Rep., (41) Annex V.4:11p.
- Métongo, B.S., 1988. Métaux lourds dans les organismes marins - Côte d'Ivoire. Report presented to Second Workshop of participants in the Joint FAO/IOC/WHO/IAEA/UNEP Project on pollution in the marine environment of the west and central African region (WACAF/2-First Phase), Accra, Ghana, 13-17 June 1988. Paris, IOC of Unesco, 20 p.
- Métongo, B.S., 1991. Concentrations en métaux toxiques chez *Crassostrea gasar* (huître de mangrove) en zone urbaine lagunaire d'Abidjan (Côte d'Ivoire). J.Ivoir.Océanol.Limnol., 1(1):33-45
- Métongo, B.S. and K.F. Kouamenan, 1991. Concentrations en mercure dans les muscles de thons albacores (*Thunnus albacares*) du Golfe de Guinée (1987-1988). J.Ivoir.Océanol.Limnol., 1(1):1-8
- Métongo, B.S. and Y Sankaré, 1990. Teneurs en métaux lourds des organes chez le crabe comestible (*Callinectes amnicola*) (décapode, Portunidae) en lagune Ebrié (Côte d'Ivoire). Agronom.Afric., 2(2):116-25
- Mhlanga, A.T. and T.J. Madziva, 1990. Pesticide residues in Lake Mcllwaine. J.Human Envir., 19(8):368-72
- Miller, S., 1982. The persistent PCB problem. Environ.Sci.Technol., 16:98A-9A
- Mitema, E.S. and F.K. Gitau, 1990. Organochlorine residues in fish from Lake Victoria, Kenya. Afr.J.Ecol., 28:234-9
- Moharram, Y.G. et al., 1987. Mercury and selenium content in bori (*Mugil cephalus*). Water Air Soil Pollut., 32:455-9
- Mombeshora, C., S.O. Ajayi and O. Osibanyo, 1981. Pollution studies on Nigerian rivers: Toxic heavy metal status of surface waters in Ibadan City. Environ.Int., 5:49-53

References

- Mombeshora, C., O. Osibanjo and S.O. Ajeyi, 1983. Pollution studies on Nigerian rivers: The onset of lead pollution of surface waters in Ibadan. Environ.Int., 9:81-4
- Mugachia, J.C., L. Kanja and F. Gitau, 1992a. Organochlorine pesticide residues in fish from Lake Naivasha and Tana River, Kenya. Bull.Environ.Contam.Toxicol., 49: 207-10
- Mugechia, J.C., L. Kanja and T.E. Maitho, 1992b. Organochlorine pesticide residues in estuarine fish from the Athi river, Kenya. Bull.Environ.Contam.Toxicol., 49: 199-206
- Mumbe, A.C., J.A. Chanda and A.S. Muleya, 1978. Aquaculture and pollution control in Zambia. Paper presented at the Sixth FAO/SIDA Workshop on aquatic pollution in relation to protection of living resources, Nairobi and Mombasa, Kenya, 12 June - 22 July 1978. Rome, FAO, FIR/TPLR/78/Inf.19:9p.
- Munga, D., 1985. DDT and endosulfan residues in fish from Hola irrigation scheme, Tana river, Kenya. MSc. Thesis, University of Nairobi, Kenya
- Nauen, C., 1983. Compilation of legal limits for hazardous substances in shellfish, fish and fishery products. FAO Fish.Circ., (764):102p.
- NAS/NAE (National Academy of Sciences/National Academy of Engineering), 1973. Water quality criteria, 1972. A report of the Committee on Water Quality Criteria. Washington, D.C., U.S. Environmental Protection Agency, (R3-73-003) 594 p.
- Ndiokwere, C.L., 1984. An investigation of heavy metal content of sediments and algae from the River Niger and Nigerian Atlantic coastal water. Environ.Pollut.(B), 7: 247-54
- Ndiokwere, C.L. and V.P. Guinn, 1983. Determination of some toxic trace metals in Nigerian river and harbour water samples by neutron activation analysis. J.Radioanal.Chem., 79:147-51
- Nitta, T., 1972. Marine pollution in Japan. In Marine Pollution and Sea Life, edited by M. Ruivo. West Byfleet, Surrey, Fishing News (Books), pp 77-81
- Norconsult, 1977. Mombasa water pollution and waste disposal study. Ministry of Local Government, Nairobi, Kenya (File "Marine Investigations")
- Nriagu, J.O.(ed), 1989. Trace metals in lakes. International Conference on trace metals in lakes, Hamilton, Ont., Canada. Sci.Total Environ., (87-88)
- Nriagu, J.O. et al., 1987. Environmental impact assessment of the iron and steel industries at Ajaokuta and Aladja. Final report. Ibadan, Nigeria, The University Consultancy Services, 177 p.
- Ntow, W.J. and M.A. Khwaja, 1989. Mercury pollution in Ghana (West Africa) coastal commercial fish. Environ.Tech.Lett., 10:109-16

References

- Nwankwoala, A.U. and O. Osibanjo, 1992. Baseline levels of selected organochlorine pesticides in surface waters in Ibadan (Nigeria) by electron capture gas chromatography. Sci.Total Environ., 119:179-90
- Ochieng, E.N., 1987. Limnological aspects and trace elements analysis Kenyan natural inland waters. MSc. Thesis, University of Nairobi, Kenya, 294 p.
- Ochumba, P.B.O., 1985. The status of lake environment in Kenya: Lake Victoria. In Proceedings of the Shiga Conference '84 on Conservation and Management of World Lake Environment, Otsu, Japan, 27-31 August 1984. Shiga Prefectural Government, pp 86-9
- Ochumba, P.B.O., 1987. Periodic massive fish kills in the Kenyan part of Lake Victoria. Water Qual.Bull., (112):119-22, 130
- Ochumba, P.B.O. and D.I. Kibaara, 1989. Observations on blue-green algal blooms in the open waters of Lake Victoria, Kenya. Afr.J.Ecol., 27:23-34
- Ogunlowo, S.O., 1991. Priority chemical pollutants in some rivers along the cocoa growing area of Ondo State. MSc. Thesis, Department of Chemistry, University of Ibadan, Nigeria
- Ogunseitan, R.O., 1987. Determination of organichlorine pesticides and polychlorinated biphenyls (PCBs) in soil and plants from refuse dumps in Nigeria. BSc. Dissertation, Department of Chemistry, University of Ibadan, Nigeria
- Ojo, O.M., 1988. Stream sediment geochemistry of Guberunde Horst, 'Gongola Basin', Upper Benue Trough, Nigeria. J.Afr.Earth Sci., 7:91-101
- Ojo, O.O., 1991. Bottom sediments as indicators of chemical pollution in Lekki Lagoon. MSc. Thesis. Department of Chemistry, University of Ibadan, Nigeria
- Okemwa, E.N., 1984. Potential fishery of Nile perch *Lates niloticus* L. (Pisces: Centropomidae) in Nyanza Gulf of Lake Victoria, East Africa. Hydrobiol., 108:121-6
- Okonna, S.I., 1985. A survey of pesticide residues in some Nigerian river waters and sediments. MSc. Thesis. Department of Chemistry, University of Ibadan, Nigeria
- Okoye, B.C.O., 1989. Heavy metals in the Lagos lagoon. Ph.D. Thesis. Ile-Ife, Nigeria. Awdowo University, Department of Chemistry
- Okoye, B.C.O., 1991. Heavy metals and organisms in the Lagos Lagoon. Int.J.Environ.Stud., 37:285-92
- Okoye, B.C.O., 1991a. Nutrients and selected chemical analysis in the Lagos Lagoon surface waters. Int.J.Environ.Stud., 38:131-6
- Okoye, B.C.O., O.A. Afolabi and E.A. Ajao, 1991. Heavy metals in the Lagos Lagoon sediments. Int.J.Environ.Stud., 37:35-41

References

- Oladimeji, A.A. and J.W. Wade, 1984. Effects of effluents from a sewage treatment plant on the aquatic organisms. Water Air Soil Pollut., 23(3):309-16
- Oliver, B.G. and M.N. Charlton, 1984. Chlorinated organic contaminants on settling particulates in the Niagara river vicinity of Lake Ontario. Environ.Sci.Technol., 18:903-8
- Oliver, B.G. and K.D. Nicol, 1984. Chlorinated contaminants in the Niagara river 1981-83. Sci.Total Environ., 39:57-70
- Onwumere, B.G. and A.A. Oladimeji, 1990. Accumulation of metals and histopathology in *Oreochromis niloticus* exposed to treated NNPC Kaduna (Nigeria) petroleum refinery effluent. Ecotox.Environ.Safety, 19:123-34
- Onyari, J.M., 1985. The concentrations of Mn, Fe, Cu, Zn, Cd and Pb in sediments and fish from the Winam Gulf of Lake Victoria and fish bought in Mombasa town markets. MSc. Thesis, University of Nairobi, Kenya, 282 p.
- Onyari, J.M. and S.O. Wendige, 1989. Distribution of Cr, Pb, Cd, Zn, Fe and Mn in Lake Victoria sediments, East Africa. Bull.Environ.Contam.Toxicol., 42:807-13
- Osibanjo, O., 1991. Physico-chemical characteristics of effluents from selected Nigerian industries. Environ.Pollut., (in press)
- Osibanjo, O. and O. Bamgbose, 1990. Chlorinated hydrocarbons in marine fish and shellfish of Nigeria. Mar.Pollut.Bull., 21:581-6
- Osibanjo, O. and S. Jensen, 1980. Ecological and environmental perspectives of pesticide pollution. In Proceedings of First National Conference on Water pollution and pesticides residue in food, University of Ibadan, Nigeria, pp 206-20
- Osibanjo, O. et al., 1988. Hydrogeological and chemical basic data acquisition from NMPC operational areas. Technical Report to Nigerian National Petroleum Corporation, Lagos
- Osibanjo, O. et al., 1994. Review of chlorinated hydrocarbon substances in the African aquatic environment. FAO Fish.Rep., (502):7-45
- Oteko, D., 1987. Analysis of some major and trace metals in the sediments of Gazi, Makupa and Tudor creeks of the Kenyan coast: A comparative investigation into the anthropogenic input levels. M.Sc. Thesis, Free University of Brussels, Belgium, 112 p.
- Paasivirta, J., H. Palm and R. Paukku, 1988. Chlorinated insecticide residues in Tanzanian environment. Tanzadrin. Chemosphere, 17(10):2055-62
- Pagès, J. and J. Citeau, 1978. La pollution bactérienne de la lagune et de la mer autour d'Abidjan. Doc.Sci.Cent.Rech.Océanogr., Abidjan ORSTOM, (11):43-50

- Pelig Ba, K.P., C.A. Biney and L.A. Antwi, 1991. Trace metal concentration in borehole waters from the Upper Regions and the Accra Plains of Ghana. Water Air Soil Pollut., 59(3-4):333-45
- Phillips, D.J.H., 1991. Selected trace elements and the use of biomonitors in subtropical and tropical marine ecosystems. Rev.Environ.Contam.Toxicol., 120:105-29
- Picer, N. and M. Picer, 1979. Monitoring of chlorinated hydrocarbons in water and sediments of the North Adriatic coastal waters. Journ.Etud.Pollut.CIESM, 4:133-6
- Pickering, G.B., J.R. Cox and L. Donegan, 1980. DDT levels in the environment following cotton spraying in the Shire Valley, Malawi, 1973-1978. London, Tropical Products Institute, Overseas Development Administration, 87 p.
- Portmann, J.E. et al., 1989. State of the marine environment in the West and Central African Region. UNEP Reg.Seas Rep.Stud., (108):34p.
- Ramesh, A. et al., 1990. Seasonal variation of persistent organochlorine insecticide residues in Veller River waters in Tamil Nadu, South India. Environ.Pollut., 67: 289-304
- Randers, J., 1973. DDT movement in the global environment. In Toward Global Equilibrium, edited by D.L. Meadows and D.H. Meadows. Cambridge, Mass., Wright-Allen Press, pp. 49-83.
- REGIDESO, 1980. Aperçu sur le secteur eau au Burundi. Présenté par la REGIDESO à l'attention de la KFK. Régie de Distribution d'Eau et d'Electricité. Bujumbura, Burundi, REGIDESO, 29 p.
- Roberts, T.R., 1985. Current trends in pesticide residue analysis. Trends Anal.Chem., 4(1):3-7
- Seed, M.A.H., 1972. Effect of pollution on the sediment of Lake Mariut, Egypt. Rapp. P.-V.Réun.CIESM, 21(3):125-7
- Saad, M.A.H., 1972a. Dissolved oxygen as an indicator of water pollution in Egyptian brackish-water lakes. In Marine pollution and sea life, edited by M. Ruivo. West Byfleet, Surrey, England, Fishing News (Books), pp 161-3
- Saad, M.A.H., 1973. Distribution of phosphates in Lake Mariut, a heavily polluted lake in Egypt. Water Air Soil Pollut., 2:515-22
- Saad, M.A.H., 1974. Influence of organic pollution on Lake Mariut, a highly polluted lake south of Alexendrie. Rev.Int.Océan.Méd., 34:23-36
- Saad, M.A.H., 1978. Core sediments from four Egyptian delta lakes. Bull.Off.Natl.Pêche, Tunisie, 2(1-2):337-45
- Saad, M.A.H., 1978a. A study on the mixed waters between Lake Edku and the Mediterranean Sea. Bull.Off.Natl.Pêche,Tunisie, 2(1-2):337-45

References

- Saad, M.A.H., 1979. Studies of the bottom deposits of Lake Brollus, an Egyptian delta lake. Cah. ORSTOM, Ser. Hydrobiol., 13(3-4):181-5
- Saad, M.A.H., 1980. Eutrophication of Lake Mariut, a heavily polluted lake in Egypt. In Agrochemical residue-biota interactions in soil and aquatic ecosystems. Vienna, IAEA, STI/PUB/548:153-63
- Saad, M.A.H., 1980a. Characteristics of sediments from three different water bodies surrounding Alexandria. Bull. Off. Natl. Pêche Tunisie, 4(2):273-82
- Saad, M.A.H., 1980b. Investigations on the bottom deposits of Lake Manzalah, Egypt. Bull. Off. Natl. Pêche Tunisie, 4(2):283-92
- Saad, M.A.H., 1980c. A limnological study of Lake Nasser and the Nile in Egypt. Water Suppl. Manage., 4:81-92
- Saad, M.A.H., 1981. Studies on agricultural residue (pesticides) and heavy metals. Biological interactions in Lake Mariut, a highly polluted lake in Egypt. Final Report, part of the Coordinated isotopic tracer aided research and monitoring programme on agricultural residue - biological interactions in aquatic ecosystems. Research Contract No 2155/RI,R2/SD, Vienna, IAEA, 126 p.
- Saad, M.A.H., 1985. Influence of pollution on Lake Mariut, Egypt III. Heavy metals. Rapp. P.-V. Réun. CIESM, 29(4):145-7
- Saad, M.A.H., 1985a. Influence of pollution on Lake Mariut, Egypt. Rev. Int. Océanogr. Méd., 79-80:33-77
- Saad, M.A.H., 1985b. Distribution of dissolved organic matter in Lake Edku during 1969-70 and 1979-80. J. Fac. Mar. Sci. Jeddah, 4:147-55
- Saad, M.A.H., 1987. Limnological studies on the Nozhe Hydrodrome, Egypt, with special reference to the problems of pollution. Sci. Total Environ., 67:195-214
- Saad, M.A.H. and M. Abbas, 1985. Limnological investigations on the Rosetta Branch of the Nile. 1. Environmental conditions. Freshwat. Biol., 15:645-53
- Saad, M.A.H. and M.A. Fahmy, 1985. Occurrence of some heavy metals in surficial sediments from the Damietta estuary of the Nile. Journ. Etud. Pollut. CIESM, 7:405-7
- Saad, M.A.H. and M.M. Kandeel, 1988. Distribution of copper, iron and manganese in the coastal Red Sea waters in front of Al-Ghardaq. Proc. Indian Natl. Sci. Acad., 54A(4):642-52
- Saad, M.A., O.A. El-Rayis and F.E. El-Nady, 1981. Occurrence of organic matter and heavy metals in sediments from the Mediterranean. In Management of Industrial Wastewater in Developing Nations. Proceedings of the International Symposium, Alexandria, March 1981, edited by D. Stuckey and A. Hemza. Oxford, Pergamon Press. pp 127-39

- Saad, M.A.H., O. El-Rayis and H. Ahdy, 1984. Status of nutrients in Lake Mariut, a delta lake in Egypt suffering from intensive pollution. Mar.Pollut.Bull., 15(11):408-11
- Saad, M.A.H., O.A. El-Rayis and F. El-Nady, 1981b. Occurrence of some trace metals in bottom deposits from Abu-Kir Bay, Egypt. Journ.Etud.Pollut.,CIFESM, (5):555-60
- Saad, M.A.H., A. Ezzat and A. Shabana, 1973. Effect of pollution on the blood characteristics of *Tilapia zillii* G. Water Air Soil Pollut., 2:171-9
- Saad, M.A.H., S.R. McComas and S.J. Eisenreich, 1985. Metals and chlorinated hydrocarbons in surficial sediments of three Nile delta lakes, Egypt. Water Air Soil Pollut., 24:27-39
- Saad, M.A.H. et al., 1982. Occurrence and distribution of chemical pollutants in Lake Mariut. 1. Residues of organochlorine pesticides. Water Air Soil Pollut., 17:245-52
- Saad, M.A.H. et al., 1981a. Occurrence and distribution of chemical pollutants in Lake Mariut, Egypt. 2. Heavy metals. Water Air Soil Pollut., 16:401-7
- Saad, M.A.H. et al., 1990. Scientific bases for pollution control in African inland waters. Domestic and industrial organic loads. FAO Fish.Rep., (437):6-24
- Saarikoski, J. et al., 1986. Factors affecting the absorption of phenolics and carboxylic acids in the guppy (*Poecilia reticulata*). Ecotoxicol.Environ.Saf., 11:158-73
- Sabljić, A., 1983. Quantitative structure-toxicity relationship of chlorinated compounds: a molecular connectivity investigation. Bull.Environ.Contam.Toxicol., 30:80-3
- Salomons, W. and U. Förstner, 1984. Metals in the hydrocycle. Berlin, Springer, 349 p.
- Sarkar, A. and R. Sen Gupta, 1988. Chlorinated pesticide residues in marine sediments. Mar.Pollut.Bull., 19:35-7
- Schmidt-Bleek, F. et al., 1982. Steps towards environmental hazard assessment of new chemicals (including a hazard ranking scheme based upon Directive 79/831/EEC. Chemosphere, 11:383-415
- Schultz, W.T., L.B. Kier and L.H. Hall, 1982. Structure-toxicity relationships of selected nitrogenous heterocyclic compounds. 3. Relations using molecular connectivity. Bull.Environ.Contam.Toxicol., 28:373-8
- Semu, E., B.R. Singh and A.R. Selmer-Olsen, 1986. Mercury pollution of effluent, air and soil near a battery factory in Tanzania. Water Air Soil Pollut., 27:141-6
- Sen Gupta, R. et al., 1990. State of the marine environment in the South Asian Seas Region. UNEP Reg.Seas Rep.Stud., (123):42p.
- Shuster, K.A., 1976. Leachate damage assessment case studies. EPA/530-SW-509, SW-514, SW-517, USEPA Cincinnati, Ohio

References

- Shuvel, H.I., 1986. Thelassogenic diseases. UNEP Reg.Seas.Rep.Stud., (79):44p.
- Smeets, J. and R. Amavis, R., 1981. Quality of water intended for human consumption. Water Air Soil Pollut., 15:483-502
- Socio, H.H. and N. Kaba, 1992. Rapport de stage sur l'analyse des pesticides organochlorés par chromatographie en phase gazeuse, janvier 1992, AIEA, Monaco. Mimeo, Abidjan, Côte d'Ivoire, Centre de recherches océanologiques, 7 p.
- Soulsby, P.G., D. Lowthion and M. Houston, 1978. Observations on the effects of sewage discharged into a tidal harbour. Mar.Pollut.Bull., 9(9):242-5
- Spregue, J.B., 1976. Current status of sublethal tests of pollutants on aquatic organisms. J.Fish.Res.Board Can., 33(9):1988-92
- Sridhar, M.K.C., 1988. Uptake of trace elements by water lettuce (*Pistia stratiotes*). Acta Hydrochim.Hydrobiol., 16:293-7
- Sridhar, M., P. Oluwande and A. Okubadeju, 1981. Health hazards and pollution from open drains in a Nigerian city. Ambio, 10(1):29-33
- Sserunjoji, J.M.S., 1974. A study of organochlorine insecticide residues in Uganda with special reference to dieldrin and DDT. In Comparative studies of food and environmental contamination. Vienne, IAEA, STI/PUB/348, pp 43-8
- Sserunjoji-Ssebelija, J., 1976. Environmental insecticide residues from tsetse fly control measures in Uganda. In Trace contaminants of agriculture, fisheries and food in developing countries. Vienna, IAEA, STI/PUB/454, pp 69-71
- Stephan, C. et al. (eds), 1983. Guidelines for deriving numerical national water quality criteria for the protection of aquatic life and its uses. Washington, D.C., U.S. Environmental Protection Agency, 57 p. (mimeo).
- Štirn, J., 1967. Assainissement du lac de Tunis. Rapport pour le gouvernement tunisien. 1/2:207p.
- Štirn, J., 1968. The pollution of the Tunis Lake. Rev.Int.Océanogr.Méd., 9:99-106
- Štirn, J., 1972. Possibilities for constructive use of domestic sewage (with an example of the Lake of Tunis). In Marine pollution and sea life, edited by M. Ruivo. West Byfleet, Surrey, England, Fishing News (Books), pp 517-9
- Štirn, J., 1973. Ecological consequences of marine pollution. In Proceedings of the Fifth International Colloquium on Medical Oceanography, Messina, 4-7 October 1971, edited by S. Genovese. Messina, Italy, Ellebi, pp 25-56
- Sunday, M., 1990. Determination of chlorinated pesticide residues and metals in sediments from rivers and streams in Ibadan, Oyo State, Nigeria. MSc. Thesis. Department of Chemistry, University of Ibadan, Nigeria

- Surma-Aho, K. *et al.*, 1986. Organic and inorganic mercury in the food chain of some lakes and reservoirs in Finland. Chemosphere, (15):353-72
- Suzuki, M., Y. Yamato and T. Akiyama, 1974. BHC (1,2,3,4,5,6-hexachlorocyclohexane) residue concentrations and their seasonal variation in the aquatic environment in the Kitakyushu District, Japan, 1970-1973. Water Res., 8:643-9
- Suzuki, M., Y. Yamato, and T. Watanabe, 1977. Analysis of environmental samples for organochlorine insecticides and related compounds by high resolution electron capture gas chromatography with capillary columns. Environ.Sci.Technol., 11: 1109-13
- Symoens, J.J., M. Burgis and J.J. Gaudet, 1981. The ecology and utilization of African inland waters. UNEP Rep.Proc.Ser., (1):191p.
- Tayel, F., 1981. Effect of pollution by pesticides on some marine animals in Abu-Kir Bay. M.Sc. Thesis, Faculty of Science, University of Alexandria, Egypt, 98 p.
- Taylor, S.R., 1964. Abundance of chemical elements in the continental crust - a new table. Geochim.Cosmochim.Acta, (28):1273-85
- Tebo, L.B. Jr., 1986. Effluent monitoring: historical perspective. In Environmental Hazard Assessment of Effluents, edited by H.L. Bergman, R.A. Kimerle and A.W. Maki. A special publication of the Society of Environmental Toxicity and Chemistry. New York, Pergamon Press, pp 13-31
- Thornton, J.A., 1981. Lake Mchlwaine: An ecological disaster averted. Zimbabwe Sci. News, 15(4):87-8
- Thornton, J.A. and W.K. Nduku, 1982. Lake Mchlwaine: the eutrophication and recovery of a tropical African man-made lake. Monogr.Biol., 49:215p.
- Thorslund, A.E., 1971. Report of survey of inland water pollution in Uganda, Kenya, Zambia and Tanzania. FAO Regul.Programme Rep., (11):16p.
- Thurston, R. V., 1979. A review of the EPA red book: quality criteria for water. Bethesda, Maryland, American Fisheries Society, 313 p.
- Tolba, M.K., 1982. Development without destruction. Evolving environmental perceptions. Dublin, Tycooly. Nat.Resour.Environ.Ser., (12):197p.
- Toma, S.A. *et al.*, 1981. The distribution of some absorbed elements on the Nile continental shelf sediments. Journ.Etud.Pollut.CIESM, 5:377-82
- Tongo, A.A., 1985. Baseline study of levels of organochlorine pesticides in Nigerian rivers and their sediments. MSc. Thesis. Department of Chemistry, University of Ibadan, Nigeria
- Train, R.E. (ed.), 1979. Quality criteria for water. London, Castle House Publishers, 256 p.

References

- Trape, A.Z., 1985. The impact of agrochemicals on human health and the environment. Ind. Environ., 8:10-2
- UNEP, 1982. Regional Seas Programme: Workplan. UNEP Reg. Seas Rep. Stud., (18):42p.
- UNEP, 1983. Action Plan for the protection and development of the marine environment and coastal areas of the West and Central African region. UNEP Reg. Seas Rep. Stud., (27):13p.
- UNEP, 1985. Action Plan for the protection, management and development of the marine and coastal environment of the Eastern African region. UNEP Reg. Seas Rep. Stud., (61):10p.
- UNEP, 1988. The Mediterranean Action Plan in a functional perspective. MAP Tech. Rep. Ser., (26):195p.
- UNEP/FAO/IOC/IAEA, 1986. Determination of DDTs and PCBs in selected marine organisms by packed column gas chromatography. UNEP Ref. Methods Mar. Pollut. Stud., (14)Rev.1:20p.
- UNEP/FAO/WHO, 1988. Assessment of chemical contaminants in food. Report on the results of the UNEP/FAO/WHO Programme of health-related environmental monitoring. Nairobi, UNEP/FAO/WHO, 110 p.
- UNEP/FAO/WHO/IAEA, 1990. Assessment of the state of marine pollution of the Mediterranean Sea by organohalogen compounds. MAP Tech. Rep. Ser., (39):1-104
- UNEP/WHO, 1988. Global environmental monitoring system. Assessment of freshwater quality. Report on the results of the WHO/UNEP programme on health-related environmental monitoring. Nairobi, UNEP and WHO, 80 p.
- United Nations, 1993. Agenda 21: Programme of action for sustainable development. Rio declaration on environment and development. Statement of forest principles. New York, United Nations, 294 p.
- U.S. EPA, 1978. Federal Register 43, 4108. Washington, D.C.
- Vandenbroek, W.L.F., 1979. Seasonal level of chlorinated hydrocarbons and heavy metals in fish and brown shrimps from the Medway estuary, Kent. Environ. Pollut., 21:21
- Van Someren, V.D., 1950. Report of the Biologist research and development centre, 1946-1947. In Review of Kenya fisheries 1946 and 1947, edited by H. Copley. Nairobi, Government Printer, pp 20-23
- Veith, G.D., D.S. Call and L.T. Brooke, 1983. Structure-toxicity relationships for the fathead minnow, *Pimephales promelas*: narcotic industrial chemicals. Can. J. Fish. Aquat. Sci., 40(6):743-8
- Vighi, M. and Calamari, D., 1985. OSARs for organotin compounds on *Daphnia magna*. Chemosphere, 14:1925-32

References

- Vivian, C.M.G. and K.S. Massie, 1977. Trace metals in waters and sediments of the River Tewe, South Wales, in relation to local sources. Environ.Pollut.(B), 14:47-62
- Vollenweider, R., 1968. Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication. Paris, Organization for Economic Co-operation and Development, Tech.Rep. DAS/CSI/ 68.27:220 p.
- Wahby, S. and M. Abdel-Mouniem, 1979. The problem of phosphorus in the eutrophic Lake Mariut. Estuar.Coast.Mar.Sci., 9:615-22
- Wahby, S. et al., 1978. Chemical characteristics of Lake Mariut, a polluted lake south of Alexandria Egypt. Estuar.Coast.Mar.Sci., 7:17-28
- Waliszewski, S.M. and G.A. Symezynski, 1982. Simple low-cost methods for determination of selected chlorinated pesticide in fat sample. J.Assoc.Off.Anal.Chem., 60:1077-80
- Welter, D.G. and G.A. Graham, 1988. Pesticide residues in fish: Prospects of a long-term monitoring program. Aust.Fish., 47(2):20-3
- Wandiga, S.O. and J.M. Onyari, 1987. The concentration of heavy metals: Mn, Fe, Cu, Zn, Cd and Pb in sediments and fish from the Winam Gulf of Lake Victoria and fish bought in Mombasa town markets. Kenya J.Sci., 8:5-18
- Ware, G.W., 1989. The pesticide book. 3rd Ed. Fresner, CA., Thomson Publ., 336 p.
- Warren, C.E., 1971. Biology and water pollution control. Philadelphia, W.B. Saunders, 434 p.
- Watling, R.J. and W.D. Emmerson, 1981. A preliminary pollution survey of the Papenkuils River. Port Elizabeth. Water,S.Afr., 7:211-5
- Watling, R.J. and H.R. Watling, 1982. Metal surveys in South African estuaries. 1. Swartkops River. Water,S.Afr., 8:26-35
- Watling, R.J. and H.R. Watling, 1982a. Metal surveys in South African estuaries. 2. Knysna River. Water,S.Afr., 8:36-44
- Watling, R.J. and H.R. Watling, 1983. Metal surveys in South African estuaries. 3. Bushmans, Kariega, Kowie and Great Fish Rivers. Water,S.Afr., 9:66-70
- Wegman, R.L.C. and P.A. Greve, 1980. Halogenated hydrocarbons in Dutch water samples over the years 1969-77. In Halogenated hydrocarbons in the aquatic environment, edited by B.K. Afghan and D. Mackay. New York, Plenum Press, pp 405-15
- Wells, C.G., 1975. Water pollution problems in Salisbury, Rhodesia: present and future. Water Pollut.Contr., 74:120-3

References

- WHO, 1979. DDT and its derivatives. WHO Environ. Health Crit., (9):194p
- WHO, 1984. Guidelines for drinking-water quality. Vol.1. Recommendations. Geneva, WHO, 130p.
- WHO, 1985. Ten years of onchocerciasis control in West Africa. Review of the work of the Onchocerciasis Control Programme in the Volta River Basin area from 1974 to 1984. Geneva, WHO, OCP/GVA/85.1B:113p
- WHO/UNEP, 1990. Public health impact of pesticides used in agriculture. Geneva, WHO, 128 p.
- Wright, R., 1982. Seasonal variations in water quality of a West African river (R. Jong in Sierra Leone). Rev. Hydrobiol. Trop., 15:193-9
- Yaméogo, L. et al., 1992. Typology of susceptibilities of aquatic insect larvae to different larvicides in a tropical environment. Chemosphere, 24:2009-21
- Zoller, W.H., 1984. Anthropogenic perturbations of metal fluxes into the atmosphere. In Changing metal cycles and human health, edited by J.O. Nriagu. Dahlem Konferenzen. Berlin, Springer, pp 27-34

This document summarizes the findings of the Committee for Inland Fisheries of Africa (CIFA) Working Party on Pollution and Fisheries. It gives advice on strategies for aquatic pollution control, including the establishment of environmental quality standards, and emphasizes the use of risk assessment to arrive at site-specific environmental protection measures. The document reviews the extent of pollution of African inland waters and concludes that, except in some hot-spot areas, it is still relatively low. Pollution by organic matter, however, causing eutrophication and anoxia, is identified as a major threat to fisheries. Although contamination with heavy metals and organochlorine substances is still low, expected increases in urbanization and socio-economic activities make it imperative to identify the sources of such material and to quantify the discharges into the aquatic environment. The occurrence of synthetic micropollutants such as organochlorine substances in different compartments of the aquatic environment, even at trace and ultratrace levels, is of ecological and environmental health concern. Pollution control strategies should be formulated in all countries to include legislation, environmental standards and criteria, waste minimization, effluent treatment, pollution monitoring, training, education and public awareness campaigns.

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